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VOLUME II

**Nutrition, Sanitation,
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FISH AS FOOD

Volume I

Production, Biochemistry, and Microbiology

Volume II

Nutrition, Sanitation, and Utilization

Volume III

Handling and Processing

FISH AS FOOD

EDITED BY

GEORG BORGSTROM

Department of Food Science
Michigan State University
East Lansing, Michigan

VOLUME II

Nutrition, Sanitation, and Utilization

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Preface

This volume is the second in the 3-volume treatise intended to review present-day fish science. The findings within this vast and important field of research are spread in innumerable scientific, technical, and trade journals, several of which are published in Russian and Japanese. This fact alone made the editing work very burdensome and furthermore revealed the inadequacies of present-day documentation and abstracting services in the food field in general, and the fish area in particular.

After having reviewed, in the first volume, the basic fields of production, biochemistry, and microbiology, this second volume proceeds to present the "public health" aspects of fish, its handling and processing. Nutrition, sanitation, and utilization are the major areas covered. A special effort has been made to convey the global aspects of fish utilization. By employing partly new concepts, a more balanced and correct picture is given, illustrating the key role of fisheries in many countries and major regions. The prevailing idea that fisheries contribute little to human feeding is substantially revamped when the character of fish as a rich source of protein and its great marginal effect in amino acid supplementation is properly considered.

Another unique characteristic of this volume is the emphasis on the risks involved in the man-induced pollution of waters through sewage effluents and radioactive contamination, fallout, and discharges. The effect on wholesomeness, preservation, and contamination is analyzed separately. Very few summaries are available on the diseases of marine and fresh-water fishes. Their economic importance is, nevertheless, at this stage largely a free guess, but unquestionably ravages by diseases and pests do occur both in lakes and oceans.

The most fundamental feature of this volume, from the public health point of view, is the mapping of the alternative ways that fish, as food, reaches the individual consumer, and also the relative significance of major preserving and processing methods. Both from the national and international point of view the whole field of fish disposition, utilization patterns, and over-all efficiency are of major concern.

This entire volume should be of considerable value not only to fish and food scientists in general, but also to public health workers, marine and fresh-water biologists, nutritionists, and sanitary engineers.

The general scope and purpose of this 3-volume treatise is presented in the preface to the first volume.

The fine cooperation of all authors is gratefully acknowledged. I am particularly indebted to Dr. Clark D. Paris, Michigan State University, for invaluable help in documentary search activities, the checking of figures and data, proofreading, editing suggestions, and finally in preparing the index. Dr. Pericles Markakis of the Food Science Department has kindly read several of the proofs and suggested improvements.

It is also a great pleasure to acknowledge the gracious cooperation of the Michigan State University Library, its Interlibrary Service, and specifically that rendered by Dr. M. Kabalin and his entire staff at the Natural Science Division.

GEORG BORGSTROM

East Lansing, Michigan
October, 1962

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CHAPTER 1

Historical Aspects of Fish

C. L. CUTTING

Humber Laboratory, Hull, England

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The rapid perishability of fish, as compared with meat, for example, has at all times and places made preservation against putrefaction an urgent necessity. Historical aspects of the various techniques that have been evolved up to the present day have recently been discussed at some length, mainly from the British point of view (Cutting, 1955). This chapter attempts to summarize the principal developments, giving special attention to recent contributions to the subject (Bridbury, 1955; Wentworth, 1956; Doorman, 1957; Chimits, 1957).

I. Early History

A. Prehistoric Times

Man has always exploited for food the aqueous phase of the earth's surface. Fortunately, early men made no attempt to dispose of refuse, and we, therefore, know from kitchen middens that shellfish have been gathered from ponds, rivers, and sea coasts since the very beginning of mankind and must, in fact, have been the chief source of animal protein in the first and much the longest food-gathering stage of human history.

The bones of fish and marine mammals, which can still be identified, testify to the advance in skill and intelligence implied by active hunting, as compared with mere collection. At a very early stage, however, men must have learned the survival value of storing day-to-day and seasonal surplus. Fish decay so rapidly that storage in itself presupposes some form of preservation. The sea fish, whose bones are found in the refuse heaps of the Late Old Stone Age cave dwellers in the Dordogne, dating from about 40,000 B.C., must have been preserved in some way to have travelled so far inland. One can only guess by analogy with the practices of primitive peoples that the process used was probably drying, either in the sun and wind when the climate was suitable, or over smoky fires. There is indirect evidence of the latter in the wood ash deposits found alongside the River Bann in Northern Ireland, which may have been the result of salmon smoking in New Stone Age times (about 2,000 B.C. in western Europe). The product might have been made into a fish pemmican, similar to that made from salmon by the American Indians of the Northwest, who first sun-dried or smoke-dried the fish, then soaked it a little before pounding finely in stone mortars, and either stored it in baskets or mixed it with oil from sturgeon or seal, after the manner of a true meat pemmican (Wentworth, 1956).

B. Bronze Age

Preservation by salt is not likely to have emerged until the Bronze Age, as its production and use imply a more highly organized economy.

The great urban civilizations of Ancient Egypt, Mesopotamia, and the Indus valley (founded about 4,000 B.C.) were based on river systems whose seasonal flooding first made agriculture possible. Although these economies chiefly depended on the organized production of cereals by irrigation systems, exploitation of the waters for fish must have played an essential role. Alongside improved methods of catching fish were developed techniques for preserving them by salting and drying. Salt fish, known as "ukas" in Egypt, was an important supplement to the staple diet of bread.

Along the Nile, fish were sometimes cut in half and suspended on ropes to accelerate natural drying in the sun and wind. Sometimes, the body of the fish is depicted in the tombs as laid open with a knife from head to tail, the two sides being divided to the backbone. In other instances, the process consisted solely of taking out the intestines, removing the head and the tip of the tail and exposing the fish, when salted, to the sun. Mackerel were not dry-salted like other fish, but were pickled in brine, as are fatty fish to this day, no doubt to protect the fat from atmospheric oxidative rancidity. Pickling was a skilled "art," associated with the priesthood. There were religious observances connected with fish-eating. At a later date, the Ptolemies held salt monopolies, and guilds of fish-salters existed. As might have been expected, fresh fish was also much eaten in Ancient Egypt, and fish intended to be consumed unsalted were sent off to market at the end of the day's fishing.

Although preservation of fish by smoke seems to have been unknown in Egypt, it was used in early Mesopotamia along with salting and drying. Dried fish were also traded from settlements on the Persian Gulf. Similarly, Mohenjo-Daro, on the Indus, was supplied with dried fish from the coast of the Arabian Sea, 150 miles away.

In the Mediterranean, the Phoenicians (about 1250 B.C.), and later the Carthaginians, were notable seafarers and colonizers. Many famous cities owed their origin to fishing settlements, including Sidon (i.e., "the fishers' town"), Gades (Cádiz), Málaga (i.e., "the salting place"), Sinope, on the Black Sea, and even Byzantium, later Constantinople.

C. Classical Times

Iron Age Greece (commencing about 1,000 B.C.) comprising so many islands, developed a considerable trade in dried, salted, and smoked fish ("tarichos") from colonies in the eastern Mediterranean from Sicily to the Bosporus. Under Roman rule (about 400 B.C. to 450 A.D.), the fish industry and the production of salt for it became still more highly organized. Colonies from southern Spain to the Black Sea, including places already famous for their fish, supplied Rome with "salsamentum," or preserved fish, of a variety of types, made from numerous classes of fish, including tuna, swordfish, sturgeon, mackerel, pike, mullet, "scarus" (a wrasse), "asellus" (hake?), bream, eel, sea-eel, oysters, and even sea urchins. Whales, seals, and sharks were also taken in the Atlantic, and the Carthaginians stayed out for considerable periods, salting at sea.

Although the classics contain a good deal of incidental commentary on fish, there is tantalizingly little detailed information on the actual methods of preservation employed (Smidth, 1876; Radcliffe, 1926; Bryant, 1954, 1955, 1956).

Plain brine seems to have been used on dolphin (not strictly a fish but a mammal, of course) and "scarus." For sea-eel (conger, presumably, or possibly even the electric eel) marjoram was added to the salt, although the lavish use of herbs and spices was condemned by some epicures. Tuna and other large fish, such as sturgeon, were cut into cubes or slices. Tuna seems to have been the most important sea fish all over the classical world, and salt fish is usually synonymous with salt tuna. Salted cubes of tuna appear to have been fairly cheap and plentiful and were preferred even to the fresh fish, which is rather tough, and was regarded as rendered more easily digestible by salting. After removing the throat and belly (as delicacies), says Pliny (A.D. 23–79), "all the rest is preserved in salt; these pieces are called 'melandrya,' as resembling splinters of wood. The cheapest of them are the parts next to the tail, because they lack fat, and the parts most favored are those next to the throat." The best cut of a Byzantine swordfish, on the other hand, was adjudged to be a "slice of the back, nearest to the tail."

One writer implies that pike was dry-salted. Although this may be no more than a stray reference and not evidence that this was the characteristic process for this species, it is, nevertheless, a fact that tuna, by comparison, contains more oil, which would be better protected from atmospheric oxidation by a brining process, whereas pike, being less oily, could perhaps better withstand dry-salting.

"Half-salt" (sometimes termed "half-fresh") cures, made from sturgeon and other species, were somewhat uncommon, probably because they were rather perishable. A half-salt mackerel removed from the brine before it was fully cured was highly esteemed, and must have resembled our "matje" herring.

"Garum," mentioned as early as Aeschylus (525–456 B.C.), was a thick sauce, or runny paste, which was originally made from the salted blood and entrails of a fish called "garon" or "garos" by the Greeks. There were numerous recipes for this preparation, the comparative merits of which were a matter of opinion. Two of the most popular were made from the gills and entrails of the mackerel and tuna. In one recipe, the blood and viscera of the tuna, among other things, were tightly packed into a vessel, which was hermetically sealed, and allowed to decompose completely (Radcliffe, 1926). The process, which presumably was largely autolytic, is similar to that used in Indochina today for the preparation of "nuoc mam." It was obviously a convenient way of dealing with smallish fish such as anchovies. The fish viscera would have furnished a potent source of proteolytic enzymes. Presumably, sufficient salt would have been incorporated to discourage anaerobes.

The greatest delicacy of all was the "garum sociorum," so-called because it was produced, under conditions of some secrecy, by a kind of fisherman's cooperative. Compounded of the intestines of Spanish mackerel, it was exported from southern Spain all over the empire. The "garum" of Mauretania (North Africa), Antipolis (modern Antibes), Pompeii, Dalmatia, Clazomenae (Asia Minor), and other places, was also highly commended by Pliny.

"Alec," like "garum," once the name of a fish (possibly the anchovy), came to signify only the sauce from it, and subsequently from other cheap fish. It differed from "garum" chiefly in being thicker, more like a paste (cf. "nam pla"), and was made, like second-grade "nuoc mam," from the residue left after the autolyzed liquor had been decanted. Brine was then added and more fish to produce a semisolid, aptly named "putrilago." With such piquant sauces, says one writer, "they drenched their subtly conceived dishes . . . so . . . that it would have been hardly possible to distinguish a fresh fish from a putrid cat—except by the bones."

Vinegar was also used extensively for shorter-term preservation. The Romans learned from the Greeks a method of preserving tuna and mackerel by first frying in oil, treating with bay leaves, salt, and spices and then pouring boiling vinegar over it. Vinegar was also used sometimes for making "garum," and was combined with salt and honey as a preservative. Cooked fish were often packed with herbs only, and although some herbs have a slight bactericidal effect, such products could have only a very limited "life."

Mullet roe, when salted, was a favorite dish, but there is no mention of caviar, made from the roe of sturgeon, until the ninth century.

Salt fish were usually packed in some form of earthenware jar, which was the commonest and cheapest container of the Greco-Roman world. The most likely type seems to have been the wide-necked wine jar, or "pithos" (also "bikos"), which stood nearly 5 feet tall. Tuna were packed in these jars "alternately," i.e., presumably head to tail, but the fish must surely have been relatively small to be able to do this.

Fresh fish could not penetrate far inland on account of poor transport and perishability. In Rome, it cost several times as much as salted fish and, as at all times in history, the "fresh" fish on sale is the butt of frequent gibes which show that it must often have been in quite an advanced state of decomposition, in spite of regulations adjuring quick sale.

Keeping the fish alive until it was to be cooked was the only sure way of obtaining really fresh fish, although such a practice could be afforded by few. This presumably was the *raison d'être* of one of the entertainments of a Roman banquet, which was to observe the color changes of red mullet as it expired, before cooking and eating it. Elaborate fresh- and salt-water fish ponds ("vivaria") were laid out to maintain supplies of live fish. The mortality was considerable and it has been suggested that the popularity of the "muraena" (related to the eel) was due not so much to its flavor as to the fact that it stood up well to fish pond existence. Fresh fish, however, were a luxury. Most people, if they tasted fish at all, did so only if it were salted, brined, or pickled in vinegar.

Rome generally was well provided with snow and ice which, as in recent times, were collected in the winter and stored in "ice-houses" until the summer. The emperors organized regular supplies from the Alps by relays of chariots. Dug-out "frigidaria," or cold stores, using ice-cold water or snow, were in use as early as 100 B.C., but there is no specific mention of their use for fresh fish.

The salt fish industry and export trade played an important part in the economic life of the ancient world. The Black Sea (or Pontus) and the Sea of Azov were particularly prolific, and have been compared in importance to the Newfoundland Banks in more recent times (Smidth, 1876). Sending "fish to the Hellespont" became a byword similar to "coals to Newcastle." In Sicily, the ruler of Syracuse built a cargo vessel to carry 10,000 jars of salt fish and 60,000 measures of grain, together with wool, freight, and provisions for the crew. Alexandria was about the only port large enough to berth it safely. In Egypt under the Empire it was almost entirely fresh-water fish that was salted and exported. If caught at any distance, it was hung up on cords to dry strung across the rigging; if nearer at hand, the dealer did the splitting, and hung it on lines to dry in the sun.

At Athens, and also probably in Rome, there existed a Society, or Corporation, of Fishmongers. Herodotus mentions salt fish ("tarichos") as an item in the diet of the Athenian army in the fifth century B.C., when it was usually eaten without cooking, apparently. Cato's not overgenerous list of the stocks of food to be laid in for vintage workers includes salt fish. However, salt fish was not overpopular and draws insulting epithets from the writers. On the other hand, fabulous prices could be paid by wealthy gourmets for fish products. One small flask of Pontic "salsamentum" could fetch more than a hundred sheep. The Licinian Law (A.D. 318) decreed certain days of the year on which only salt fish could be eaten.

Recipes for using salt fish involve washing with water and cooking with various seasonings, such as cheese, or sauces made from eggs, wine, honey, oil and herbs. Salted mullet was boiled or fried in oil.

Fish cakes were made from "tursio" (possibly either sturgeon, porpoise, or dolphin). A kind of fish sausage, "insicia" or "isicia," was also held in great favor in Rome.

II. Middle Ages

A. General

During the Middle Ages the center of gravity of the fishing industry of the western world shifted from the Mediterranean to the more prolific North Sea, where the course of development can be taken to epitomize the general pattern of events. Right up until the railway era, commencing about 1840, salting, drying, and smoking remained the staple methods of long-term preservation, with "potting" in vinegar for shorter periods. It was discovered empirically that certain sequences and combinations of treatments possessed special advantages in the particular geographical, technological, and social environment in which they had to operate. It is, therefore, possible by the end of the Middle Ages to distinguish, amidst numerous variants, certain distinct processing patterns, which became fixed over comparatively long periods of time. Thus, in the North Atlantic countries, methods of salting and drying, whether combined together (as in dried salt cod, etc.), or with smoking (as in "red herring") or alone (as in salt pickled herring and wind-dried cod—"stockfish") have persisted practically unchanged for a number of centuries down to the present day.

Drying and salting also held, and in fact still hold, the stage throughout Asia. Marco Polo (about 1300) and later Hakluyt (about 1600) gave accounts of the salting of tuna, etc., on the Arabian Sea and Persian Gulf and the drying of salted sturgeon and the preparation of caviar from its roe on the shores of the Caspian Sea.

Throughout the Middle Ages, and for long after, fresh fish was mostly of fresh-water origin and very expensive. Practically every species inhabiting river, ditch, and millstream, even the tiny minnow, was eaten, and ponds, or "stews," were kept artificially stocked for the well-to-do. "Coarse" fish, such as pike and tench, were transported alive by road to London as late as the eighteenth century. Sea fish were also brought to port alive in boat bottoms wherever possible. Most of the population, however, ate only hard-dried, salted, and smoked products, and though at coastal villages mildly cured varieties were prepared for local consumption, the slowness of medieval transport, whether by land or water, confined trade to products that could be kept for several months without going bad.

Practically all species of sea fish and shellfish were preserved for eating, but the principal catches were white fish, chiefly cod and related species, such as haddock, whiting, and hake, which are plentiful in the North Sea and adjacent waters and which can be taken more or less all the year round; and the herring and pilchard family, which are more abundant, but very seasonal in occurrence and subject to natural fluctuation from year to year.

In England, Hull, Grimsby, Scarborough, and Whitby, and the Norfolk coast on the east of England, Barking and Greenwich in the Thames estuary, Rye and Winchelsea on the south coast, and Devon and Cornwall in the southwest were already noted for fish from the twelfth century onwards.

All types of fish, including turbot, plaice, and dogfish, were preserved by salting, but drying was confined mainly to the leaner species of white fish. Herring, and also salmon, are rich in oil and prone to oxidation, with resulting rancid flavor, and could not, therefore, be preserved for very long by simple drying, even with salt. They kept much better if the access of atmospheric oxygen was impeded by covering with a strong salt brine in a tight vessel, such as a wooden barrel. Rancidity could also be retarded by the antioxidant affects of wood-smoking.

B. HERRING

1. *Salt Herring*

a. BALTIC INDUSTRY

Although salt herring were an object of trade at North Sea ports as early as the seventh century A.D., they were first prepared on a really large scale at Scania (Schonen) at the western end of the Baltic during the twelfth century, where the trade was organized by North German merchants from the ports of the Hanseatic League.

The earliest products probably consisted merely of ungutted herring sprinkled or strewn with salt ("steurharing" in Dutch) in irregular heaps on the ground. "Ghescudde harinc" ("roused" herring), lightly sprinkled with salt and turned over and over, are mentioned at Dordrecht in the thirteenth century. Such fish were transported in wickerwork baskets (or "Korven," hence "Korfharing," or "corved herring," in English). Such methods would do little more than delay putrefaction, and if distribution took longer than a few weeks the condition must have been very questionable. Often such fish were hard-smoked as soon as possible to confer an additional few weeks' life. This was the case with the Baltic "Strohbücklinge" ("hart geraucherte Bücklinge in Korben mit stroh verpackt") and the equally hard-smoked "Kappeler Bückling" (from Kappeln near Kiel), both ancestors of the more sophisticated and milder smoked Bucklings of Bornholm and elsewhere at the present day. The Dutch, too, made a similar smoked product, called "bokking," for home consumption only.

b. IMPROVED METHODS OF SALTING HERRING

Controversy still rages as to whether Hanseatics or Dutch initiated the radical improvements in the process during the fourteenth century, as a result of which salt herring became the foremost mass-produced food of the late Middle Ages, and the Dutch the pre-eminent producers. Since a recent review (Cutting, 1955), interesting new evidence has been presented by Doorman (1957). Beukels of Biervliet, a village on the West Schelde, then part of the county of Flanders, is traditionally associated with the revolution in technique which gave the Netherlanders the undisputed lead for the next few centuries. It seems incontestable that the Dutch had something to do with such innovations as eviscerating the fish prior to salting and the use of wooden barrels to hold fish covered in brine in place of the open wicker baskets, a development credited to the fishermen of the Zierikzee on the East Schelde. Thus, from 1252 onward "tonharing" (barrel herring) is mentioned in connection with a toll at Zwin, and a document of 1320 refers to "harenc in tonniaus," and although this was probably still ungutted "steurharing," if the fish were covered with brine the resulting protection from oxidative rancidity, and the rather different osmotic balance of a product coming to equilibrium in a salt solution, would have resulted in a more attractive commodity. Another tradition associates the shift of the center of activity from Scania to Zeeland early in the fifteenth century with a change in the habits of the herring in the Baltic. But although there may well have been some long-term fluctuation from natural causes characteristic of the clupeoid family, it is quite certain that the Baltic herring fishery did not in any sense disappear. Thus, in 1432 and 1445 yields were apparently excellent; in 1463, 20,000 men are reported to have been involved in rioting between Danes, who did the fishing, and Germans, who did the curing; there are records of gluts of herring at Scania in the years 1485-1486 and 1492-1494; and in the eighteenth century again Sweden had developed a considerable herring industry—indeed, she still has at the present day. It has been suggested by Bridbury (1955) that the basis of this legend of the decline of the Baltic herring catch is the decline of the native North German salt industry for other reasons (see Section II, B, 4). Nevertheless, it is quite possible that the economic changes coincided with, and may have been affected by, a lull in the fishing, even although the latter was not the determining factor. The latest picture of the facts as seen through the mists of time and polemic seems to be somewhat as follows. Sometime between 1315 and 1330, i.e., the best part of a century earlier than hitherto established, an important innovation, known as "haringkaken," was introduced in Flanders, possibly by the Willem Beukels who is mentioned in papers of 1308 and 1312 and appears to have been a man of some substance, although there is no direct documentary evidence that he had anything to do with herring-curing. "Kaking" consisted of gutting herring by a cut with a special knife just behind the gills by means of which the stomach, heart, liver, and part of the intestine and gills were taken out with one movement, leaving the head on and the pyloric caeca intact. The importance of retaining the latter appendages was perpetuated armorially in the heraldic device of the village of De Rijp, which, in a plaque dated 1652 now in the museum at Rotterdam, shows two "kaked" herring with part of the intestines attached to the cut.

"Kaken" seems to mean "jaws" and, in this sense, "gills." "Kaecharinx" is first mentioned in 1332. Subsequently "kaken" (and the cognate French "caquer") became synonymous with the salting and barreling of herring.

This operation of partial gutting, or "gipping" as it was eventually termed in Britain, had two advantages. First, it was much quicker than a complete gutting process, speeds of up to 40 fish per minute being attainable with practice. This in itself enabled the process to be carried out at sea on the fishing vessel and thus rendered the Dutch fishermen pursuing the prolific fishery off the British coasts independent of shore bases at Yarmouth and elsewhere, which held many unsatisfactory features. Second, the proteolytic enzymes of the pyloric caeca were active even in saturated salt solution, softening the flesh and producing a characteristic and much relished "gamey" or "cheesy" flavor, which was something new in medieval provender, and is still today an attraction to those that have acquired the taste. Apparently herring caught in the Zuyder Zee did not mature in this way and were therefore disposed of fresh, or used for "bokking," thus commanding a lower price. The lag between the actual invention of 1315 to 1330 and the flourishing of the method in the following century can be attributed to opposition inspired by the German Hansa and Flemish merchants associated with it (and admitted by them in a letter dated 30th June, 1425), who saw a threat to their trade in Baltic herring, which in the event was largely taken over by the fishermen of the neighboring Zeeland islands.

This effective way of dealing with large quantities of fish was geared to a highly productive fishing technique, using sizable vessels (termed herring "busses" from Dutch herring "buizen") operating as "factory ships" and employing a "vleet" (Anglicized to "fleet") consisting of upwards of 50 nets. The often-quoted statement that the large herring net ("grote net") was first made at Hoorn in 1416 (which is derived from Velius' "Chroniick van Hoorn," running until 1630) can be interpreted to mean no more than that whereas previously small ships landed there inshore herring (caught in the Zuyder Zee, for example) which were used fresh or smoked, in that year ships first sailed from Hoorn into the North Sea using the "great net." This does not necessarily mean that people did not earlier than this sail from other ports on the North Sea with large ships and large nets. Evidence to the effect that the "great net" was not an invention of Hoorn in 1416, but was known earlier, seems to be afforded by the records of complaints from named skippers of Flemish ships in 1314, 1317, and 1318 that they have been robbed of 40, 45, or 55 nets "with ropes," suggesting that their fishery along the English coast was based on the drift net. However, it was in the early part of the fifteenth century that the Dutch fishing really established itself.

c. The Scania Fishery

The alternative view has it that the improved technique was developed at Scania and then transferred to the North Sea fishery, perhaps by Beukels, and possibly accelerated by a sequence of poor seasons in the Baltic. Dutch vessels from the Zuyder Zee and Ijssel towns certainly participated in the Scania herring trade in the twelfth and thirteenth centuries. Danish fish on Scania appear to have been packed in barrels with salt when they were not dried or smoked. In 1262, herring were traded in barrels, but whether gutted or salted whole is not known. "Grumagield," mentioned in 1339, was the profit from the herring offal, from which herring oil was obtained, but again whether from surplus herring or viscera from "kaking" is not apparent. However, by 1365 the Dutch overseer from Kampen on Scania is instructed to see that the "ghelleconen" (literally "gall-wives," i.e., "gutting women") were well paid. There were also "leggheconen" ("laying women," i.e., packers into barrels). In 1379, the English, too, asked for permission to gut and salt herring on Scania, but it is not known whether this gutting was in fact "kaking" or some other treatment, or whether it had been borrowed from the Dutch or vice versa. In any case, the course of events showed that the various improvements in technique fell on the most favorable soil for their fullest organization and exploitation in Holland, although for some considerable time the Baltic industry was proceeding along parallel lines, based, however, on curing on shore from a small-boat fishery. The Hansa merchants were able to maintain and regulate quality of product and thus protect its reputation.

After the fish were brought ashore, they were eviscerated, washed in sea water, "roused" in salt, and finally packed with salt in barrels. The barrel, when full, was allowed to stand for 10 days, after which the herring had sunk a little as a result of shrinkage due to osmosis, so the barrel was then opened and refilled. Hanseatic laws forbade the placing of small or inferior herring in the middle of the barrel and the fish had all to be salted alike and packed in regular layers. "Full" herring, containing fully developed roe or milt, were distinguished from "Spents," i.e., those which had just spawned. At first the fish were exported in the barrels in which they had originally been packed, but later on, the majority were sent to the Hanseatic towns to be sorted and repacked in specially stamped barrels. In 1375, at a conference at Lübeck, the "Rostocker Band" was adopted as the standard measure.

d. Dutch Salt Herring

The Dutch Grand Fishery, which monopolized the herring trade of Europe for several centuries, was prosecuted off the Shetland Islands and northeast Scotland in the summer and East Anglia in the autumn, where herring still congregate at the same seasons today. The "buss" carried a crew of about fifteen men, including skilled picklers and coopers, together with the nets, salt, and barrels required for a season's work, which resulted normally in a production of about 35 to 40 "lasts" (a "last" comprising 12 barrels, totalling about 2 tons). At the peak of this industry, in the first half of the seventeenth century, there were probably about 2000 of these busses employed, Enkhuizen alone having 700 in 1637. Nearly half a million persons were employed directly or indirectly, or one-fifth of the total population; hence it was said, figuratively, that Amsterdam was "built on herring bones."

Although there was a certain amount of secrecy about the precise practical details of the Dutch process, it can be seen from their public ordinances that the underlying reason for the predominance of this Grand Fishery was once again the strict system of "quality control" with stringent regulations defining standards for product and process, providing for severe penalties, e.g., a month on bread and water (1651). Various legislation was promulgated by successive rulers from the Counts of Flanders to the Holy Roman Emperor, Charles V. The Dutch Republic consolidated this legislation, and in 1620 the College of Fisheries was invested with full powers to make regulations and settle disputes. The College met annually at Delft at the beginning of each season to decide on the date for the commencement of the fishing (which was related to the "quality," and in particular, probably, the fattiness of the fish), to issue instructions and grant licenses.

The sequence of operations, which is exactly the same as is still used to this day, bears a strong resemblance to that already described for the Baltic. Immediately after the herring had been shaken out of the drift net onto the deck of the ship, they were "gipped," and then sprinkled with salt and "roused," sorted and packed regularly head to tail in barrels with salt sprinkled between the layers, which were arranged alternately across one another. Finally, the barrels were topped up and made airtight (to minimize oxidative rancidity) and branded with the date of catch. The barrel of Brielle, in the northwest corner of the island of Voorn, was adopted as the standard. All herring had to be taken back to the Netherlands for branding (by specially swift vessels, "ventjagers," from about 1602 onward) and could not be sold at sea or shipped directly to foreign markets. First-caught herring could not be sold until they had been in pickle for at least 10 days. Repacking on shore had to be completed within three weeks of landing. The number and size of staves for making barrels were specified, and not more than three pieces of wood were allowed in the bottom of the barrel. Only dry, heavy wood could be used, and all faulty barrels were broken up. The use of old barrels was strictly prohibited. Any fault in the packing which could have resulted in the brine leaking out would have let in air and the consequent oxidation would have been fatal to the reputation of the product.

The packing of poor-quality herring along with good herring was severely forbidden, but the former could be packed separately provided they were correctly labeled, as for example "nachtshamel" (i.e., "overdays"), and "kuytsieck" or "melksieck" ("ripe-running," or "mazy," i.e., so close to spawning that the milt is squeezed out over the fish on capture). No one, according to a Placart and Ordinance of 1651, should lay the herring crosswise (thereby giving poor weight for measure), or falsify or change them, put the old under new, lay those bitten by dogfish or ones that were "sickly" along with sound fish, nor pack fish which were caught on one night with those of another night's taking. No herrings could be "heightened" with fresh pickle, nor packed but in the public street, on the quays, or in "such places as are customary with open doors," thus facilitating inspection. This carefully controlled technique resulted in a keeping quality of 12 months in any climate. The Dutch could thus distribute their product up all the principal rivers of Europe from the Vistula to the Seine, but especially up the Rhine, Meuse, and Schelde. Such pickled herring was one of the first foodstuffs to become a major item of international trade, and thus revolutionized the economic conditions of the time.

e. Rise of British Fishery

Successive British government from Elizabethan times onward made various attempts to encourage the development of a herring industry around our coasts by systems of subsidies (called "bounties"). The Dutch fishery did not survive the wars of the late seventeenth and eighteenth centuries, and Swedish products ousted the Dutch in importance. It was not until after the Napoleonic Wars that Scotland was finally able to establish a native industry, backed by government supervision of quality by a system of "branding" with a hot iron the barrels containing fish of the required quality. Within a century, first through the pre-eminence of the sailing drifter and aided just before 1900 by the change over to the steam drifter, Britain became the greatest herring-curing nation in the world. Pickled herring salted on shore and exported chiefly to eastern Europe accounted in 1913 for some 300,000 tons of a total annual catch of 550,000 tons. Following the two World Wars, however, this trade has declined to the merest shadow of its former magnitude.

2. *Smoked Herring*

One of the earliest mentions of the smoking of herring relates to Fécamp in 1230. The relation of the German Bückling and Dutch "bokking" to the more important salt herring industry has already been indicated. Britain, however, while not competing to any extent with the Dutch in the production of salt herring (also known as "white" herring), developed a characteristic hard-salted, smoked, and dried ungutted product, called the "red" herring, although the product after cold-smoking for some weeks was dark brown rather than red. In fact, "black" herring was another name for it, and, "blackhouses" for smoking are mentioned in an English will of 1349. After salting, the herring are given a preliminary soaking before smoking; otherwise, the drying results in excessive salt crystallization. The Statute of Herrings in 1357 set out maximum wholesale prices and profit margins for the sale of "white" and "red" herring at Great Yarmouth, which early became the most important center for the production of "reds." Thomas Nashe, the poet and contemporary of Shakespeare, who was born at Lowestoft, wrote in 1599 a curious work entitled "Lenten Stuffe; containing the description and first procreation and increase of the towne of Great Yarmouth, in Norfolke; with a new play never played before of the *Praise of the Red-Herring*." In it he says that "it is most precious merchandise because it can be carried through all Europe. Nowhere are they so well cured as at Yarmouth. The poorer sort make it three parts of their sustenance." However, he observes that "reds" did not keep as well as salt herrings, presumably because the physical barrier to fat oxidation presented by complete submersion in brine was more effective than the chemical barrier provided by the phenolic antioxidants absorbed from wood smoke.

Two reasons given (in 1670) why the Dutch did not capture the British trade in "reds" as they had that of salted herring were that the fish had to be brought to the land to be cured, as at Yarmouth, which the Dutch could not do; and that they must be smoked with wood, whereas Holland was not a woody country, although this argument is not very convincing, as one would have imagined from its activities in shipbuilding that there would have been ample supplies of fuel to support a fish-smoking industry, as is indeed evidenced by the "bokking." Furthermore, they were in fact producers of red herring.

Allowing for the unreliability of production statistics until recent times, Daniel Defoe (the author of "Robinson Crusoe") writes in 1724 of Yarmouth that "the merchants . . . have cur'd, that is to say, Hang'd and dry'd in the smoak 40,000 barrels of merchantable red herrings in one season," each barrel containing about 1,000 herring (i.e., a total of about 7,000 tons). Scottish summer herring have always been regarded as less suitable for "redding," being fattier, softer, and subjected to higher temperature than the East Anglian autumn herrings, "which makes it more difficult to cure them so as to keep in a hot country and on a long voyage . . . as to Venice and Leghorn." The demand for "reds" in Mediterranean countries continues unabated at a much more stable, though lower, level than the trade in pickled herring. Yarmouth is still a major producer and so are the Dutch, using methods that have changed little in centuries, although with more rapid transport the product today is becoming somewhat less hard and salty than that of former times.

3. *Other Fatty Fish Products*

Although "white" and "red" herrings were the outstanding products, there were numerous other allied products. Pilchards were preserved in Cornwall, either by smoke ("fumadoes," corrupted to "fair maids"), or by salting in barrels combined with pressing to remove surplus oil. There were also various intermediate products, such as the "bloater," which contained more salt, but had less smoking than the "red." Salmon, too, were either smoked to produce the original of the "kipper," or salted in barrels, in which they were conveyed with the brine produced.

Fatty fish were also subjected to less severe processes using vinegar, with or without a cooking process. Salmon, trout, and char "potted" in this way for short-term storage were popular in the eighteenth century, as "Newcastle salmon," for example. Herring, treated with spices of various sorts, and known as "Marinaden" became popular on the continent, particularly in Germany and Sweden which still consume a variety of such "semi-conserves." Toward the end of the nineteenth century, an export trade developed in "Klondyked" herring, which were merely sprinkled with salt after icing in boxes for a quick journey to Germany, where they were mostly smoked as Bückling or marinated.

4. *Salt for Fish Curing*

Salt was a key commodity throughout the Middle Ages, largely because of its importance in the preservation of herring. Prior to about 1350, there were three main centers of production in western Europe, and it is no coincidence that each of these was situated in close proximity to a center of the herring fishing industry (Bridbury, 1955). Scania herring were treated with salt made at Lüneberg, where natural brine was drawn from wells in buckets and boiled over fires of brushwood and faggots in rectangular caldrons made of thin iron sheets as described by Agricola (1556). This process was expensive in labor, materials, and fuel. In the Low Countries, they used salt extracted from the peat impregnated by the action of the sea. This material, termed *darinck*, or *zelle*, dug from the banks and marsh flats, was first dried or burnt, the ash was dissolved in salt water and the solution evaporated in small light-weight pans over turf fires to produce a fine white salt. The island of Tolen was a great center for this industry, which, however, could only be followed in the summer months. So great did this industry become in the fourteenth and fifteenth centuries that restrictions had to be imposed, first at Brielle, and then elsewhere, to protect the dikes from being undermined. In fourteenth-century England, salt was produced from the brine springs of Worcestershire and Cheshire, and also from sea water practically all around the coast, but chiefly in Lincolnshire, Norfolk, and Sussex.

From about 1350 onward, these local industries were largely supplanted by the output of salines along the Biscayan coast, but chiefly by the "Bay Salt" from the Bay of Bourgneuf between Brittany and Poitou, where sea water was allowed to evaporate continuously in shallow lagoons by means of solar heat. The product, however, was very crude and in particular would have contained calcium and magnesium salts. The Dutch, therefore, developed a method of dissolving away these impurities by boiling in sea water. This "salte-upon-salte" ultimately replaced the more-expensive-to-produce native products in the Baltic, Dutch, and English herring-curing industries.

C. WHITE FISH

1. *Stockfish*

Of the white fish products, available in the Middle Ages, the most primitive was stockfish, which was plain sun- and wind-dried, whole, gutted cod, and similar species, produced notably in Norway and Iceland. After some 6 weeks or so, the water content was reduced to about 15%, below which even molds can no longer multiply. In the course of the prolonged drying process considerable spoilage occurs, accompanied by a strengthening of flavor which was no doubt a not unwelcome feature considering the monotonous medieval dietary, and stockfish is still relished today by the initiated who have acquired the taste for this product in the form of a dish called "lütefisk," made after soaking in lye. The climate of the northerly countries with a cold, dry, and sunny spring was advantageous for the evolution of such a product, which would have decomposed excessively if subjected to higher temperatures and humidities, not to mention the attentions of blowflies in warmer weather. German merchants handled the Norwegian product from the twelfth century onward, and finally about 1350 the Hansa established its office at Bergen, where cod liver oil ("tran" or "train oil") for illumination and leather dressing was also an important by-product. This monopoly lasted until 1550 when Hanseatic power finally collapsed. The trade in stockfish, however, has persisted down the centuries in a remarkable manner and still accounts for a large export from Norway and Iceland to the Mediterranean countries, particularly Italy, the Scandinavian element in the United States and, since the early years of the present century, to West Africa, particularly Nigeria (as "Afrikafisk").

Not until the seventeenth century did the Norwegians learn from English merchants how to salt and dry cod, although by the end of the fifteenth century they had adopted the Dutch method of wet-curing herring.

2. *Salted Cod*

a. ICELAND

Iceland was first visited by English merchants early in the fifteenth century, trading their goods in exchange for stockfish, e.g., three fish for a pair of ladies' shoes, fifteen for a firkin of honey, etc. Fish was defined as "piscis durus vocatus stockfysch." English line fishermen, too, began to sail from Thames and East Anglian ports for a season lasting from February or March to October or November, in vessels carrying from 5 to 10 men along with a summer's provisions and supplies of salt. Although the industry was known as the "Stockfischery of Yseland" (Hakluyt, 1589), the use of salt shows that the method employed in this instance was not simply one of drying alone but salting at sea. At the end of the season each vessel hoped to bring back all the cargo of salt absorbed into about 15 lasts (30 tons) of fish which would in many cases be dried and kept for sale in Lent. It could be kept subsequently for a year or more if properly dry.

Throughout the fifteenth century, many flourishing little English ports, now sadly derelict and silted up, sent their quota of ships on this "Iceland trade." A writer at the end of the sixteenth century attributes the prosperity of Hull largely to "their trade in Iseland-fish, dry'd and harden'd, term'd by them Stockfish; which turns to great gain and has strangely enrich'd the town."

However, there was constant political trouble with the King of Denmark. It is clear from contemporary accounts that Tudor voyages of discovery to Muscovy, Greenland, etc., had the dual objects of promoting trade, in English woollens for example, and of discovering lucrative fishing grounds.

b. THE NORTHWEST ATLANTIC COD FISHERY

The discovery of Newfoundland in 1497 by Cabot on an expedition financed by Bristol merchants was no exception. It was reported on his return "that the sea there is swarming with fish (chiefly cod) . . . (and)

. . . that they could bring so many fish that this Kingdom would have no further need of Iceland." However, although the French, Portuguese, and Spanish were soon fishing on the new banks, it was not until the end of the sixteenth century that the English southwest ports really obtained a footing, literally with the occupation in 1583 of Newfoundland itself, partly with the object of securing drying grounds for English fishermen to cure their fish.

The French had access to plenty of solar salt, made by the evaporation of seawater in the Biscayan marshes. They therefore went in for the "green" fishery, or "core" fishery, as it was also called, the fish being brought back and sold wet but permeated with salt. According to a typical account their process was as follows. The fish after landing on deck were placed on narrow tables where one man cut off the heads and threw them in the sea, a second cut open the bellies and eviscerated them, and a third cut out the backbone, after which they were passed below deck to the salter. On the bottom of the hold, fish were arranged head to tail and covered with a layer of salt. Successive layers of fish were laid on top and similarly salted until the end of the day. After the fish had been left three or four days and the brine formed by the water drawn out of the fish by the osmotic action of the salt had been drained away, the surplus salt was removed and the fish were put down in new layers and covered with new salt as before. After this "Kench-curing," as it became called in North America, the fish were ready to be taken back to France where it seems they were sold in barrels because it was said of the English at the end of the sixteenth century they "had not the use of barrelling up of cod, and if it be not barrelled it is not vendible in France." It was chiefly consumed in Paris during Lent.

British fishermen were short of suitable salt, and at first traded with the Portuguese fishermen (who "made all wet" fish but "dried it when they got home") for their surplus. They therefore made a less salty cure, which had to be dried in order to complete the preservation. The history of the New World was largely influenced by the requirements of the cod-salting industry and the international rivalries that resulted. In the early seventeenth century, New England was first colonized by some fishermen because the climate was more suitable for drying than that of Newfoundland, and in addition there were numerous rocky beaches on which to lay out fish. The French, when driven away by the English from the coast of Newfoundland, discovered the prolific Grand Bank. They also settled in Cape Breton Island, Nova Scotia, and the Gaspé Peninsula, but the climate there was poorer and fish had commonly to be dried on hurdles, known as "flakes," because of the lack of suitable beaches. The rivalry between English and French fishermen was not the least of the causes of the War of the Spanish Succession and the Seven Years' War. Under the provisions of the Treaty of Utrecht (1713), the French were allowed "to catch fish and to dry them on the land" only on the west coast of Newfoundland, which was less favorable climatically. The Treaty of Paris (1763) led to their forcible eviction from Cape Breton, although they were still allowed a foothold on St. Pierre and Miquelon. On the less accessible Gaspé Peninsula, the combination of climate and shortage of salt led to rather a hazardous cure, with what has come to be regarded as a specially attractive flavor to the present day.

With the French threat finally removed, the friction between England and New England came to a head. One of the bones of contention was the mother country's determination to monopolize the West Indian trade. New England, perhaps on account of the warmer climate, produced a high proportion of unmarketable salt fish, which was used to feed the plantation slaves, who were not, however, too servile to complain about this "refuse fish." After the Declaration of Independence, the House of Representatives of Massachusetts at Boston in 1784 decided in a resolution "to hang up the representation of a cod fish in the room where the House sits, as a memorial to the importance of the cod fishery to the welfare of this Commonwealth."

D. CONSUMER ASPECTS

Dried and salted fish were sold under a number of popular names, the origin and meaning of which is often obscure. "Lochefisshe" sold at Blakeney (Norfolk) fish fair in 1357 was apparently of three types, "lob," ling, and cod, while "orgeys" were fish larger than "lob." Unspecified "pecys of salt fisch" are a common entry in the account books of Bristol merchants. "Poor John" (referred to in Shakespeare's "The Tempest") seems to have been chiefly small cod or hake. "Stockfish" occurs in "Henry IV" and "old ling" in "All's Well that Ends Well."

"Haburden" or "haberdine," possibly so called from the Basque province of Labourd, was a larger variety of hard-dried salt cod. "Millwell" or "mulvel" was probably something similar, perhaps made from whiting. "Ling," although a definite species, was a term apparently used for dried fish generally. "Mudfish," like "green fish," was undried, wet salted fish. "Bacalao" was the Spanish word for dried salted cod.

Throughout the eighteenth and nineteenth centuries, salt was heavily taxed in Britain, as in most other countries. This led to all sorts of complications for the fish industry.

Although in the sixteenth and seventeenth centuries there were in England religious injunctions, backed by political expediency, to enforce the regular eating of fish, which for most people meant the hard-smoked, salted, and dried products, numerous literary allusions make it obvious that these were consumed with resignation, because they were all that was available, rather than enthusiasm.

III. Modern Era

A. THE RISE OF THE FRESH FISH TRADE

1. *Introduction*

Most people, at all times, have preferred fresh fish to salted, smoked, or dried fish if given the choice. Consequently, the history of the development of the fishing industry in modern times has been a succession of attempts to keep fish fresh between catching and consumption. The following account relates to the experience of Britain in particular, but the same general pattern of development was followed in North America also. Roads were bad until the beginning of the nineteenth century and transport either by packhorse or by water was so slow that such perishable goods as fresh fish could not penetrate very far from the port.

2. *Live Fish*

One way of diminishing the effects of the well-known perishability of fresh fish is to keep it alive until the last possible moment. Bringing sea fish to port in the live state developed into a large-scale industry in the North Sea in the eighteenth and nineteenth centuries and somewhat later in New England. "Well-vessels," consisting of large tank amidships in which holes were bored to allow free circulation of sea-water, were introduced at Harwich from Holland about 1712. Soon after this, Daniel Defoe noted similar "fish pools" at Barking, which was thus able to land fish alive at Billingsgate for the London market. In the second half of the nineteenth century, Grimsby became the premier port for the "live fishing." Hull was too far up the Humber estuary to participate, as the water was too fresh.

The fish were caught on baited hooks fitted with a gorge to prevent swallowing, thus minimizing internal damage. They were handled carefully and thrown into the tank tail first so that they did not break their necks. Cod was the principal species brought back in this way. If caught at not too great a depth, it survived the change in pressure on being brought to the surface and could normally be kept alive in the well for a week or so. The swim-bladders, which were distended after catching, had to be punctured so that the fish could right themselves. Flat fish, which lay on the bottom and blocked the holes, were stowed in boxes. Large predatory fish, such as skate and halibut, were tethered by a cord at the nose and tail respectively. Fish that died were removed daily and salted or, later on, iced. At port, fish were taken from the well by means of a net and transferred to large crates, called "chests," which floated anchored in the harbor. Each chest held 40 to 100 fish, according to size, which could be kept for a further week or two without adverse effect. Up to 400 such chests were in use at Grimsby. These "live cod" were highly esteemed in London and a large fish would sell at Billingsgate for over £1. New England ports similarly for a period developed a flourishing trade in live halibut.

However, although there still continues to be a small trade in live sea fish, in Norway and Denmark for example, the process has obvious limitations. The revolution in technique, which, in the second half of last century converted fresh fish from an expensive luxury into a staple food of the poorer classes, was associated with the spread of trawling, the use of ice, and rapid transport by rail. Since about 1850, therefore, the market for salted fish has declined in industrial countries, although the total world demand for such products has by no means decreased and in the case of salt cod still accounts for over a half of the total catch of that species.

3. *Trawling*

Catching fish by dragging a net over the sea bottom had been a method practiced since the fourteenth century in sheltered waters such as the Thames estuary and the Zuyder Zee. By the end of the eighteenth century the fishermen of Barking and Brixham were having success in coastal waters with a much larger net of this type, kept open by means of a beam of wood. They extended their operations to the North Sea and discovered rich fishing grounds, to exploit which they settled at Hull, Yarmouth, etc. Trawling was a more productive method of fishing than lining. The fish, however, were mostly dead when they were landed on deck and they could be distributed in sound condition to centers of population inland only if they were handled expeditiously, as by "fleeting," or if chilled by means of ice. Small fish, otherwise unwanted, were absorbed in Britain by the growing number of fried fish shops, which vended cheap food to the masses. Small haddocks found an outlet as "finnans."

4. *"Fleeting" and Steam Power*

The firm of Samuel Hewett (1797-1871) of Barking, which owned a number of North Sea sailing trawlers, first organized the system of fishing as a fleet, under an "admiral," in which the catch from every ship was collected daily and sent to Billingsgate market by special, swift, cutterrigged carrier-vessels, which after 1864 were steam-powered. The trawlers themselves continued for some time to be sail-driven, despite a number of sporadic attempts to apply steam power to them from about 1860 onwards. After a period in which steam paddle-tugs of the rivers Tyne and Wear were used to assist the trawlers when it was too calm, the tugs themselves began to be fitted with trawls about 1877. Steam-powered capstans and winches, too, made operations at sea easier and further increased productivity. The first successful steam trawlers were built in 1883, and steam drifters for herring soon after. Fleeting survived the transition from sail to steam trawling and continued from Hull, although on a decreasing scale, until the 1930's.

5. *Icing*

All these improvements in the productivity of fishing led to the need for improved methods of preservation, and this was met in the first instance by the use of natural ice. The first use of ice to preserve fish during transport was in 1786 when, following a report by a captain of an East Indiaman that it was commonly used in China, salmon were first sent from the North of Scotland to London packed in ice in boxes. The ice was collected from lochs during the winter and stored in earth houses. Such ice is also reported to have been used for herring just before 1800 and it was becoming common in the normal fresh fish trade by about 1820.

About mid-century it began to be used systematically by Hewett's for the preservation of fish at sea. Ice from the Thames marshes was collected as a crop by the farmers and brought in carts to a large store at Barking. Ice-lugs then took it out to the cutters in the river, for use in the "fleeting" operations. When trawlers operated on their own ("single-boating"), supplies of ice were scarcely adequate for requirements, and it had to be used sparingly and only on the most valuable species. "Offal fish," including plaice and haddocks, often had to be thrown overboard for lack of ice. Hull and Grimsby trawlers first started using ice about 1860, relying on increasing imports from Norway. By 1900, however, factories were erected at the ports for making ice artificially for supply to the fish trade. More ample supplies made it possible for British trawlers to go farther afield in search of fish, thus developing distant but prolific trawling grounds off Iceland (1891), Barents Sea (1905), and Bear Island (1920's). Larger steam trawlers with constantly improving fishing gear, such as the otter-trawl (1895), steel warps, Vigneron-Dahl trawl (1920's) and more recently the echo-sounder, radar, etc., have brought back greater and greater quantities of fish, although in some areas, such as the North Sea, the intensity of fishing effort has led to a reduction in the yield per unit of effort to a barely economic level. In addition to Britain, such countries as France, Germany, and Iceland have similarly developed an Arctic fishery with large trawlers, while others have continued either to exploit principally coastal waters (as in the case of Norway) or at most engage in 8- to 10-day fishing trips to the grounds and back (as in the case of Canada). British distant-water trawlers average something like 20-day trips, including, say, 5-day trips each way, to and from the grounds. However, even with the use of ice to delay decomposition, there are difficulties in landing and marketing this distant-water fish in fresh condition, with the result that the sanitary authorities take a regular toll of a per cent or so of the supplies, and a proportion of that which is passed as fit for human consumption is of indifferent quality.

B. Fish Meal

The filleting of white fish at the ports developed greatly in the mid-1920's, to some extent perhaps an expedient for marketing distant-water cod which would often have appeared stale and unsavory if despatched with head, gills, belly-wall, etc., intact. This development led to an industry for the organized collection and treatment of the filleting offal, by drying and grinding into a meal for animal fodder. Increasing demands for such a protein supplement for stock feeding were also met by the drying of whole fatty fish, such as herring, where surplus to the normal requirements of trade and distribution, usually after a process of cooking, followed by pressing to remove the majority of the oil, which is also a valued product.

C. Fried Fish Trade

The large quantities of small fish, first produced by trawling operations in the 1840's, were bought up and marketed cheaply by itinerant costermongers amongst the industrial proletariat. This, too, seems to have been the origin of the fried fish trade, so characteristic of Britain. Charles Dickens (1838) mentions a "fried fish warehouse" in a "narrow and dismal alley" in Holborn. Little capital was required to start in business, it was reported by Mayhew (1861), only a "frying pan 2s. (secondhand 9d.), tray 2s. 6d. (secondhand 8d.); salt box 6d. (secondhand 1d.); and stock money 5s. 0d. in all 10s. 0d. A man has gone into the trade, however, with 1s. 0d., which he expended in fish and oil, borrowed a frying pan (and) . . . an old tea board."

Today a major proportion of the trade in British distant-water cod fillets is marketed by the widely distributed fried fish trade.

D. FREEZING

The freezing of fish by natural means has long been known as a method of preservation in countries with cold winters, such as Russia, Siberia, and Canada. Also in the Great Lakes area, this method of weather freezing was common. In Newfoundland, herring were allowed to freeze in the open air for subsequent use as bait.

Such stiff-frozen fresh fish were also marketed commercially and are still encountered in the north of the Soviet Union. At the start, various mixtures of ice and salt were employed for the freezing of fish on a commercial scale. This was the case in 1865 in the United States (Tressler and Evers, 1957). Soon after the invention of the machine compressor, this was put to use for freezing food, and experimentation, primarily with meat and fish, paved the way for its industrial use. This happened simultaneously in Western Europe, the United States, and Russia. At the end of the century, fish freezing was quite important in the United States and Russia (Zaitsev and Pavlov, 1958; Stevenson, 1899). Some enterprises were also operating in Western Europe (the United Kingdom and Scandinavia) at this time. Some frozen fish also trickled into the world market. In 1880, freezing machines were installed on barges which were towed along the Volga from Astrakhan up this river collecting raw material for the canning industry. Similar practices were applied in the Yenisei River fisheries in 1905 (Zaitsev and Pavlov, 1958).

It is likely that the quality of this frozen fish reaching the retail market was not entirely satisfactory. The classic histological work of Plank *et al.* (1916) and Reuter (1916) demonstrated the need for freezing this tissue quickly in order to minimize damage to the structure and texture. Largely as a result of this discovery, an industrial development started between the two wars by such pioneers as Harnsworth (1925; quoted in Huntsman, 1931), Birdseye (1929), and Zarotschenzeff (1930), directed toward devising special plants for commercial freezing.

At the start, fish were frozen whole. Later, filleting was introduced. This was done almost simultaneously in the United States and the Soviet Union (Astrakhan and Murmansk). "Quick-freezing" resulted no doubt in a great improvement over the former process of merely placing fish to freeze slowly in cold stores, often in large wooden boxes which further retarded the removal of heat. However, there was for a period a tendency to place undue emphasis on "quick freezing" and its associate problems of packaging as the sole guarantee for excellence.

Further patient scientific work in the 1930's in a number of countries led to the realization that frozen fish needed cold storage at a distinctly lower temperature than was regarded as acceptable commercially for meat and other foodstuffs. Not until after 1945 did this principle begin to win wide acceptance in industry.

For a country with a distant-water fishery, such as Britain, the establishment of a freezing industry on shore obviously cannot be expected to result in a material improvement in the quality of the fish marketed, except insofar as it can smooth out day-to-day and seasonal surpluses and eliminate the deterioration that inevitably occurs during normal distribution in the fresh state. The freezing of fish at sea on the fishing vessel or on a "mother-ship" has been attempted from time to time since the late 1920's as a means of preserving fish better during the voyage home and thus facilitating the exploitation of the distant-water Arctic fishery. The latest British and United States developments in this field are described in Volume III, Chapter 25.

E. Mildly Smoked Fish

Just as the advent of the railway network in Britain in the 1840's made possible the rapid inland distribution of fish in the fresh, unpreserved condition, so, too, the development of less heavily smoked products can be associated with the same period. Thus, the red herring of former times gave way to "Newcastle Kippers" (invented 1843) and "Yarmouth bloaters" (about 1835). "Finnan haddocks," originally a local product made on a domestic scale near Aberdeen, provided an outlet for surplus, trawled haddocks landed at London and Hull (where smokehouses were erected in 1847) and Grimsby (1856). Both Yarmouth bloaters and "finney" haddock were already conspicuous amongst the "dried fish" (i.e., smoke-cured fish) on sale at Billingsgate in 1851.

On the continent of Europe a preference developed for hot-smoked products, such as the Bornholm Bückling, which likewise replaced the earlier, much-harder-cured Baltic product.

In all these products the chief purpose of smoking is to impart an agreeable flavor, the shelf-life at ordinary temperatures being only a few days in most cases. In recent years, the tendency towards ever lighter and milder-smoked products has continued with the result that the smoke serves more as a condiment than as a preservative. The development of freezing, particularly in consumer packs, which in itself effects the preservation, has furthered this trend. The accepted degree of coloration of the "fully" smoked kipper, etc., is in most cases maintained by the use of artificial coloring. This practice is at least 60 years old (Stevenson, 1899), such colorings as saffron and annatto having now been superseded by various "permitted" coal-tar dyes, although in some countries, notably the United States of America, the practice is not allowed, on the grounds that it represents a deception of the consumer.

F. CANNING

Canning was the result of an attempt to preserve satisfactorily without adversely affecting palatability by undue desiccation, toughening, and salting.

Fish and lobsters were among the preserved food delivered by Nicholas Appert to the French government soon after the publication of his method in 1810. His results aroused interest in Britain, and several firms were soon canning salmon, trout, lobsters, etc., in Scotland. An Aberdeen firm supplied Parry the explorer with victuals in 1824. In order to obtain higher temperatures for quicker sterilization, sodium chloride, sodium nitrate, and calcium chloride were first added to the heating bath to raise its boiling point. Although anticipated by Papin's "digester" (1681), cooking under pressure was first employed about 1840, and not until 1875 were proper steam kettles devised, the forerunners of the modern retort.

Fish canning was introduced to the Atlantic seaboard of America by English immigrants and the tin "cannister," invented in 1810, first received its abbreviation "can." in New England about 1840. These "cans." were hand-made by tinsmiths from sheets of tinplate (60 being a good day's production), until the pressed-out, open-topped, "sanitary can" was developed toward the end of last century, and thereafter mechanization proceeded apace.

Canning of Pacific salmon, from small beginnings in 1865, later supplied one of the principal canned commodities entering world trade, spreading to Japan and Siberia. Canned "sardines" (immature pilchards) cooked and packed in oil, which were supplied from Nantes for a sea expedition as early as 1822, became the second main line of canned fish, later extending across the Mediterranean to Morocco. Norway originated about 1880 a similar process, involving light smoking for sprats ("brisling") and immature herring ("sild"), and smallish fish in other parts of the world are treated in a like manner.

In the last 20 years the pack of salmon has suffered a curtailment consequent upon the fall-off in catch, and tuna, not canned before about 1900, has now replaced it as the leading pack of the world, mostly produced in the United States.

Mature herring, pilchards, and similar species are also canned on an appreciable scale. Other species, such as lobsters and oysters, although canned from the beginning, have remained at a relatively low level, restricted by availability and price.

Although fish canning originated and first established itself on an empirical basis, by the turn of the century the need exerted itself for a scientific study of the bacteriological problems posed by the canning of lobsters, among others, and canning continues to be one of the most rationalized and scientific sections of the fish industry.

IV. The Future

At all times the rapid perishability of fish has constituted a problem for the human race, although the degree of pretentiousness as regards freshness has varied considerably with time and place.

All the methods of preservation referred to above appear capable of continued application and further development. Salting and drying, either individually, in combination, or along with heavy smoking, although superseded in the most advanced countries, promise to have a long lease of life still in relatively undeveloped parts of the world where communications are poor and climatic conditions severe.

Even in Western European countries, considerable improvements are possible in the application of chilling to preserve freshness to the utmost during distribution. Furthermore, the economic advance of countries at present underdeveloped will make enormous demands on ice as an agent for retarding spoilage. In fact, the industrial application of present knowledge of temperature control, combined with what is now only common-sense hygienic handling (using common sanitizers such as chlorine) would probably result in a greater ultimate improvement in short-term preservation than, for example, the possibilities opened up by the use of antibiotics as adjuvants to ice. Similarly, although revolutionary new methods of preservation, such as perhaps radiation sterilization, or some superdehydration, combining perfect reconstitutability with good storage properties, may some day radically alter the situation, the extended application of existing methods of freezing and canning for long-term preservation could satisfy all reasonable needs for many years to come.

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Fish Protein—Nutritive Aspects*

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[*] Note: The untimely death of the senior author of this chapter occurred in the fall of 1959. Dr. Geiger had outlined his contribution and written part of it in rough draft. This was sent to the editor who took it upon himself to complete the manuscript. Since the original plan was that Dr. Geiger, then the director of research for the Van Camp Seafood Company, would write this part of the book, the junior author had not been working too closely with him. Consequently, he hopes to be forgiven for any omissions or changes that might not have been contemplated by its original author, as well as for the selections of papers now included in this final text. I am most indebted to Dr. H. L. A. Tarr, of Vancouver, British Columbia, and S. Lassen, of Terminal Island, Los Angeles, California, who graciously consented to read the finished manuscript, for their valuable suggestions.

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I. Introduction

Experience over many centuries has established the fact that ethnic groups who obtain their meat supplies from the oceans, rivers, or lakes are well nourished. In the northeast of Brazil, for example, De Castro (1952) has pointed out that the predominant constitutional type among the natives varies with the kind of protein available. The tall, healthy type of individual can be found either along the coastline where large quantities of fish are consumed, or in the cattle-raising backlands where the intake of animals protein is also high. In the intervening jungle zone, however, where cassava or manioc flour serves as the dietary staple, the short type predominates.

A similar study is that of Brock and Autret (1952), who report that "Basse Gasamance in Senegal, lying between Gambia and Portuguese Guinea, is an area in which there is plenty of fish, crabs, and oysters . . . and there are no serious food deficiency states and no kwashiorkor in children," although protein deficiency was endemic in nearby areas where fish did not form the basis of the diet.

Other well-organized medical surveys have also demonstrated the adequacy of fish as the principal source of dietary protein, and repeated and thorough laboratory investigations have confirmed these empirical findings. Fish is also generally inexpensive in comparison of other protein foods (Taylor, 1953). Nevertheless, many housekeepers and even workers in the field of human nutrition continue to regard fish only as a substitute for meat, to be introduced into the menu because of its lower cost, easier availability, or culinary value. This distinction is also preserved in both the Jewish and Christian dietary rituals, which allow the consumption of fish at times when the consumption of meat is prohibited.

Early systematic investigations of the nutritive value of fish stimulated by the meat shortage that occurred during World War I were made possible by the concurrent development of adequate analytical and feeding methods. These early experiments found that the nutritive value of fish was equal to that of meat and also recognized that fish oil represents a good source of calories and provides many important vitamins. The nutritional standing of fish increased particularly in the twenties and thirties when it was established that fish contained large amounts of the then newly discovered vitamins A and D. But due to the increased production of caloric resources in the form of more palatable and less expensive vegetable and animal oils and the introduction of synthetic vitamins, the nutritional importance of fish today rests largely upon the fact that it is an excellent source of protein of high biological value.

Recent medical investigations have shown that insufficient intake of protein or the consumption of protein that failed to provide the essential amino acids are most significant factors in human malnutrition and that a supply of suitable protein is the chief limiting factor of good nutrition on all continents. In addition, the breeding of commercially important animals depends upon the quality and quantity of dietary protein. Consequently, the recognition that fish contain proteins or superior nutritional properties places them in an especially important category of foods.

This review will take into consideration only such parts of the fish as are commonly eaten. This means predominantly flesh. Many studies are available on visceral and other body organs as to their protein composition and general characteristics. These will not be included.

II. Protein Content

The amount of protein in fish is influenced by the fat and water content, and the determination of fish protein is liable to a number of errors of measurement. The relative amount of flesh is another decisive factor.

The amount of flesh in fish has been evaluated in many species by Reay *et al.* (1943) and van Wyk (1944). This varies with size, age, sexual state, or season of capture. The yield obtained for fillets without skin usually varies between 40% and 50% according to species. Van Wyk (1944) found that the amount of flesh constituted 50 to 60% of the total weight of the fish. From this it may be concluded that the relative amount of muscular tissue is generally higher in fish than in domestic animals or in man (Hamoir, 1955).

Jacquot and Creac'h (1950) compiled several such yield figures. Other evaluations have been made on Spanish fishes (Rodríguez de la Heras and Méndez-Isla, 1952), Indian fishes (Airan and Joshi, 1952) and the Pacific saurel (*Cololabis saira*) (Tsuchiya *et al.*, 1953). See also Chapter 6 by Jacquot in Volume 1.

There is an inverse relationship between the fat and protein contents of the edible part of one and the same fish. This has been reported by several research workers (see Chapter 5). There are, nevertheless, findings to the contrary, as, e.g., in Obst (1938). The fat content may vary between 0.3 and 17% or more. Generally, the lean flesh has a higher protein content and a greater culinary value, and better keeping qualities, due to the low levels of unsaturated fats, which are subject to rancidification even at low temperatures. There are, however, many exceptions. Salmon, for example, in spite of its relatively high fat content, is quite acceptable from the culinary standpoint.

The protein content of fish also varies with the water content. Although this does not affect the nutritional qualities of the fish, it may influence its dollar value. It is desirable, therefore, to express the protein content of fish in terms of percentage of dry substance. The protein calories in different fish are expressed as the per cent of total calories in Table I.

TABLE I
PROTEIN CALORIES IN PER CENT OF TOTAL CALORIES OF CERTAIN FISH VARIETIES OF SOME OTHER COMMON FOODS

Food	Per cent
Cod, edible portion	95
Bass, Atlantic, black	89
Albacore	90
Bass, sea, white	93
Flounder	95
Haddock	96
Sole	85
Halibut, Atlantic	66
Salmon, King (canned)	43.5
Herring, Atlantic	41.5
Sardine, Atlantic (canned)	21
Pork meat (medium fat, cooked)	13.9
Beef meat (medium fat, cooked)	27.4
Beef meat (lean)	69
Chicken meat (total edible)	25.5
Chicken, white meat only	76
Egg, whole	33.9
Milk, skimmed, dried	42.7
Cheese, cottage	76

It may be seen that the muscle of some lean fish contains exceptionally high levels of protein even when compared to the best meats. Inclusion of such fish in the diet offers a convenient and inexpensive method of increasing the protein content without increasing the total fat intake, as recently proposed in certain therapeutic regimes, and of supplementing diets containing proteins of lower nutritional value.

The relationship between fat and protein valid for one and the same fish and discussed above does not apply when comparing one species with another. This is evident from Table II, covering major selected fishes. A serving of fish consequently may vary appreciably as to its content of calories, protein, and fat. Even closely related species, e.g. the various salmon, may show basic differences in protein content. The chum salmon is consistently highest (21.5%) in protein content (see tabulation below), while the pink salmon is lowest (19.5%). These fundamental differences do not seem to be directly connected with the fat content (Dewberry, 1951).

TABLE II
PERCENTAGE COMPOSITION OF FISH FLESH
(Raw when not otherwise indicated)

Fish species	Calories per 100 g.	Protein	Fat
Sardine, Atlantic	338	21.1	27.0
Tuna (canned)	290	23.8	20.9
Salmon, Pacific	223	17.4	16.5
Salmon, king (canned)	203	19.7	13.2
Herring	191	18.3	12.5
Eel	162	18.6	9.1
Halibut	126	18.6	5.2
Swordfish	118	19.2	4.0
Mackerel	102	11.0	6.2
Haddock	79	18.2	0.1
Sole	67	13.0	1.3
Cod	60	14.6	0.6
Smelt	60	11.3	1.6
Turbot	43	8.8	1.3
Whiting, Atlantic	43	11.3	0.1

Salmon	Total solids[a] (%)	Fats[a] (%)	Protein[a] (6.25 N) (%)
Chum	30.0	5.0	21.5
Coho	32.5	8.0	21.0
Spring	36.8	12.5	20.0
Sockeye	35.2	9.3	20.0
Pink	30.2	6.4	19.5

[a] Source: Dewberry, 1961.

The extensive data published in the literature concerning the protein content of fish indicate that the different types of fish contain widely

TABLE III
REFERENCES TO SELECTED STUDIES ON PROTEIN CONTENT OF FISH[a]

Country	References
Africa	
Cape Verde	Busson *et al.*, 1953
Cameroun	Bergeret and Masseyeff, 1957
America	
Canada	Bailey, 1942
United States	Sinnhuber *et al.*, 1956
Rockfish	Thurston, 1961
Salt-water fish	Teeri *et al.*, 1957
Pacific ocean perch	Iversen, 1958
Fresh-water fish	Thurston *et al.*, 1959
Mexico	
Miscellaneous	Massieu *et al.*, 1954
Peru	
Salt-water (chiefly)	Sánchez Moreno, 1950
	Rodríguez Velasco, 1950
	Sandoval Colmenares, 1951
	Horna Acosta, 1951
	Vásquez Vassalo, 1951
	Vallejos Plantano, 1952
	Zanona, 1951
	Arévalo Padilla, 1952
	Castillo la Rosa Sánchez, 1952
	Costa Saenz, 1952
	Urco Nájera, 1953
	Cisneros, Almontes, 1953
	Córdova Urteaga, 1953
	Mock Morales, 1953
	Zambrano Royes, 1953
Both fresh- and salt-water fish	Collazo Chiriboga *et al.*, 1952
Asia	
Ceylon	Lantz and Gunasekera, 1957
Pakistan	Qureshi, 1951
Philippines	Intengan *et al.*, 1956
All kinds	Sulit *et al.*, 1953
	Valenzuela, 1928
Vietnam	
All kinds	Nguyen-thi-lau and Richard, 1959
India	
Salt-water	Niyogi *et al.*, 1941
	Setna *et al.*, 1944
	Chari, 1948
	Airan *et al.*, 1950

[a] References not encountered in generally available compilation of data.

TABLE III (*continued*)

Country	References
Asia (*continued*)	
	Airan, 1950; 1951
	Venkataraman and Chari, 1951
Sardine	Hornell and Ramaswami, 1924
Fresh-water (Bengal)	Basu and De, 1938
	Saha and Guha, 1939
Europe	
Germany	Skudd, 1936
Roumania	
Fresh-water (chiefly)	Vintilescu, 1940
Spain	
General (47 species)	Rodríguez de la Heras and Méndez-Isla, 1952
Sardine	Fernández del Riego, 1948
Saurel	Arévalo, 1948
Soviet Union	
Sakhalin (herring)	Levanidov, 1950

varying amounts of protein, ranging from 92 to 30% of the dry solids, or even less. Several earlier and recent listings of protein analyses in fish are reviewed in Volume I, Chapter 6 by Jacquot and Chapter 11 by Simidu. Besides Atwater's study in 1891, a U.S.D.A. bulletin by Langworthy (1898) merits mentioning. The following recent compilations should also be consulted: Love *et al.* (1959) and Leung *et al.* (1952).

Unfortunately, as pointed out in reviews by Geiger (1948) and by Jacquot (1950), most of these results have only limited value. One of the most conspicuous errors is inadequate sampling (Stansby, 1953). In many of the investigations, the samples were usually small in number, did not represent the whole fish, and neglected such important factors as the age and sex of the fish, seasonal variations, and the geographical location of the catch. A listing of major studies giving data on the protein content of various food fishes has been prepared (Table III).

It has recently been demonstrated (Karrick *et al.*, 1956) that the protein content of the fresh-water drum varies between such values as 14.5 and 19.9%, and in the Siskowets lake trout the range is still greater—5.9 to 17.8%. A more limited range was found in Pacific rockfish (17.3–20.8%) with no correlation between size of specimens, season of capture or handling (Thurston, 1961). The necessity of analyzing the whole fish is emphasized by Dontcheff and Legendre (1938), who found that different parts of the albacore contained varying percentages of protein. This naturally depends on whether edible or not. Red or blood meat, for example, contains more fat and less protein than white meat. Examinations by the senior author gave the values shown in Table IV.

TABLE IV
ANALYSIS OF PRECOOKED TUNA MEAT (by Geiger)

Species	Moisture (%)	Protein (%)	Fat (%)
Yellowfin (large)			
Light meat	66.6	32.2	0.6
Dark meat	66.7	31.0	1.3
Yellowfin (small)			
Light meat	67.1	31.0	0.7
Dark meat	66.7	27.6	2.6
Skipjack			
Light meat	67.5	30.0	0.3
Dark meat	66.4	28.7	2.2
Albacore (Japan)			
Light meat	68.1	30.0	1.2
Dark meat	67.4	28.9	2.5

Tuna fish caught off the Cape Verde islands held the highest protein figures for all foods of animal origin, namely 22.5% (Busson *et al.*, 1953). Setna *et al.* (1944) analyzed a number of marine fishes from Bombay and found the protein content to vary between 15 and 25%. Chari (1948) reports on Madras coast fishes, varying between 14.5% protein for sardine, 22.9% for a shark ("sauru"), and 23.8% for a tuna (*T. macropterus*). A special feature is the extraordinarily high protein figures for a number of cheap, despised species, while several fishes considered delicacies show lower figures. Several fishes belonging to this latter group are seasonal, while the neglected species are available the year round, and constitute the cheapest animal protein available on the food market (Setna *et al.*, 1944). Pakistan fishes also show greater variation from 9.1% in Bombay duck to 24.1% in "mahseer" (Qureshi, 1951). Philippine fishes vary between 15.7 and 23.9% protein (Valenzuela, 1928). Regional food fishes in Vietnam show a range of 13 to 25% (Nguyen-thi-lau and Richard, 1959). The highest values are attributed to "cathu" (*Cybium commersoni*).

Data by Bailey (1951) indicate that the protein content of halibut showing the defect of "chalkiness" is higher as compared to that of normal halibut. Consequently, chalky halibut is, from a nutritive standpoint, unexpectedly superior to normal halibut, unless some as yet unrecognized factor might partially invalidate this conclusion.

The reverse phenomenon is characteristic for the so-called "jellied" condition in the flesh of many large North American plaice, rendering them unsuitable for the market. Jellied fillets have, on the average (in percentages of total weight), over 4% more water and over 4% less protein than normal fillets. In the jellied fillets the myosin fraction is reduced and the stroma fraction increased in terms of percentage of the total nitrogen. It was concluded that parallel with the jellying went a protein emaciation caused by the gonads having priority in use of protein. Many large plaice in the colder-water areas are incapable of providing for body repair and growth and at the same time keeping up the development of sexual products (Templeman and Andrews, 1956). A jellied flesh also occurs after attacks by some protozoans (see Chapter 14, Volume I).

Plankton-feeding fishes appear to show higher protein values than fishes feeding otherwise (Marinkovič and Zei, 1959). Hibernating carp show a decrease in both protein and free amino acids. Two-year-old specimens had a slightly different flesh protein composition as compared to one-year specimens (Sorvachev, 1959). Information on such causal relationships between feed with respect to food organisms, and the final flesh composition of the fish, as well as the effect of other ecological factors, is extremely scanty. This field merits extended research. Koval'chuk (1954b) found no seasonal variations in the serum protein components of two cultivated fish species. The total protein content and the albumin concentration in both were lower in the cold season (water temperature 9–14°C.), when the motility and food intake were low, than in warm season (17–23°C.). The variation of the total serum protein content appeared to be more dependent on that in the albumin fraction than in the globulin fraction. This may indicate that the albumin fraction is more closely related to the nutrition and metabolism of fish and that it is readily variable. Wild fish contained more hemoglobin, greater total serum protein content and higher serum albumin concentration than did the cultivated ones. In the warm season, when the food intake and motility were large, the composition of serum proteins of cultivated fish aproached that of wild fish. The findings are important to the artificial raising of fish for methods of procuring a nutritionally equivalent product.

An error is frequently introduced into the values for protein content through the determination method itself. Most authors, particularly in nutrition experiments, determine the nitrogen content of the fish by using the Kjeldahl method. They multiply the values obtained by 6.25 to derive figures representing the protein content, based on the assumption that fish protein contains 16% nitrogen. This method was recently critically reviewed by Dietrich (1956), who suggested that, on the basis of his examination of herring, it would be more correct to use a factor of 5.72. This error is confounded by the fact that the determination of total nitrogen includes several fractions that differ nutritionally from muscle protein. An example is the noncoagulable "gelatin-type protein" of low biological value, which apparently is found in fish, but not necessarily more than in other meats. Present are, however, other "extractives," including substantial amount of free amino acids. Strictly speaking all these additional nitrogenous compounds do not represent true protein. They amount to 9–14% of the total nitrogen in flatfish and gadoids, 14–18% in the herring group, and 34–38% in the elasmobranchs (see special tables, Walford and Wilber, 1955). This error becomes particularly apparent in this last fish group, where much of the nitrogen occurs as urea. Protein calculation in this case may be seriously misleading, as in the case of dogfish (Stansby, 1953).

The nature and quantities of such extractives have been discussed by Jacquot and Creac'h (1950), Tarr (1958), and Shewan (1951, 1955). Certain of these substances, such as the amino acids and noncoagulable proteins, are capable of participating in the production of other amino acids. These are nonessential amino acids since various fishes studied lack the ability of synthesizing amino acids belonging to the indispensable group. In addition, other biologically important compounds may be formed. All these constituents may in turn contribute to the biological value of the true protein. It is also conceivable that free amino acids may not only supplement existing proteins but also participate in their actual synthesis. All these factors may influence a true evaluation of a fish protein—both negatively and positively. The extracted protein may show lower values than they exhibit when actually consumed in the fish flesh together with the pool of amino acids. Other compounds such as urea are, unless given to ruminants, nutritionally almost inert. Atwater (1892) investigated gelatinous material of a proteinaceous nature, which accounted for a substantial part of the protein (19.5% of total protein in the herring, 16.4% in the haddock, and 5.5% in the salmon). Such gelatinous material, which has a low nutritional value by its own merit, could, however, be important as a supplement.

So it is evident that when the protein content of fish is determined without correcting for the presence of noncoagulable protein and nonprotein nitrogenous substances, an error is introduced into feeding experiments which may seriously affect the results, i.e., the biological evaluation of a particular fish protein source. It would be desirable to determine the distribution of total nitrogen present in the edible portions of the more important varieties of fish in order that corrections could be made in the final nutritional calculations of such experiments.

For some fishes the total amino acid content is given, without a clear distinction between protein-bound and free acids. Such separate values are available, for instance, for the Manila sea catfish (*Aurius manillensis*) (Galvez and Santos, 1932). The change in composition with age has been studied in a few instances (Manon, 1937).

Several studies are available concerning the biochemical characteristics of fish muscle proteins (Weber, 1933; Roth, 1947; Hamoir, 1953, 1955) (see also Chapter 9 by Dyer and Dingle in Volume I). These investigations are not taken into consideration in this review, unless they are essential to an understanding of the nutritive merits of fish. Indications are that elasmobranchs lack albumin (Irisawa and Irisawa, 1954). The curative effect by tradition ascribed to fish blood may possibly be explained by recent findings by Drilhon and Fine (1957). They discovered that most fish contain high relative amounts of globulins as compared to albumins. Such fresh-water fish as carp and eel are, when well fed, very potent sources.

One important finding deserves mention. In two fresh-water fishes—perch and pope—the carbohydrate figures as percentage of protein are high (3.2–4.4%). In addition, 0.4–1.0% glucosamin was found. Several sulfur- and glucosamin-containing mucins and phosphoproteins were also reported (Schormüller and Ballschmieter, 1951).

III. Methods of Appraisal

The methods for evaluating the nutritive value of fish proteins follow closely those that have been developed for proteins in other food commodities. No effort will, therefore, be made to survey these procedures. Reference is merely made to some important reviews (Mitchell, 1944, 1946; Block and Mitchell, 1946; Allison, 1949, 1955; Spector *et al.*, 1954; Nilson, 1955; Miller, 1956; Anonymous, 1956; Adrian and Rerat, 1958), and major papers in this area (Kokoski, 1947; Kühnau, 1949; Allison, 1951; Carpenter, 1951; Oser, 1951; Mitchill, 1954; Miller and Bender, 1955; Bender and Doell, 1957; Carpenter, 1958; Harding-Charçonnet *et al.*, 1958; Chapmann *et al.*, 1959; Nehring and Wünsche, 1959). The methods for establishing the amino acid requirements of man have also been improved, indicating variations in this respect with regard to age, sex, physical condition, etc. (Leverton, 1954; Anonymous, 1958a; and several others). In transferring the findings from basic evaluations into practical application, the digestibility enters into the picture as a determining factor (see two following paragraphs); so does availability (Linkswiler *et al.*, 1958). The simultaneous presence of other nutrients also has a modifying effect of sparing or accelerating the use of protein (Geiger, 1951).

Miller, together with Bender (1955), developed the concept of the coefficient for net protein utilization (NPU). This is related to the biological value (BV) and digestibility (CUD) in the following way: NPU = BV × CUD. Bender and Doell (1957) reported good correlation between the protein efficiency ratio (PER) and net protein utilization. Miller's method is less time-consuming and less laborious than the classical Mitchell method for determining the BV. A similar shortened version was later presented by Njaa (1959).

Recently, Sheffner *et al.* (1956) described an *in vitro* method for a pepsin digest-residue (PDR) index that purports to measure accurately the net utilization value or biological value, multiplied by the digestibility of food proteins. This new procedure takes into account not only changes in total amino acid content, but also the enzymic availability of the component amino acids. In 1959, Chapman *et al.* presented a new, more reliable bioassay method for evaluating protein efficiency ratios (PER).

Due to amino acid absorption losses on the paper chromatograms based on the color produced by reaction with ninhydrin, such analyses are not very precise. A simple, rapid method for the quantitative determination of amino acids in protein that eliminates this difficulty was presented by Yermakova in 1957.

IV. Biological Value

Systematic investigations of the nutritive value of fish proteins were initiated in 1918 by Drummond. He isolated the proteins of herring, cod, and salmon by means of heat coagulation in an acid medium, followed by consecutive extractions with water, hot alcohol, and ether. This protein extract was determined to be as effective as beef protein and superior to casein in promoting the growth of rats when fed at a 6% level. Drummond came to the conclusion that because of its nutritive value fish should figure prominently in the diet of the British nation as a "substitute" for meat. In 1919, Suzuki *et al.* found that sardine protein fed at a 5% level maintained the normal weights of rats and that a diet containing 7% skipjack protein promoted a normal growth of young rats (see also Suzuki *et al.*, 1920). At the same time in the United States Holmes (1918) conducted the first experiment to determine the nutritive value of fish protein in humans. Although these experiments were not designed in an entirely satisfactory way, the author was able to conclude that fish (butterfish, Boston mackerel, grayfish, and salmon) represents food of high digestibility and nutritive value for the purpose of human nutrition. Kik and McCollum (1920) maintained, also on the basis of rat experiments, that fish was not quite as effective in maintaining growth as were beef, kidney, or liver protein.

Investigations in the following years confirmed these earlier findings. Kik and McCollum (1927) investigated the quality of haddock and herring protein and found that both produced a satisfactory growth, but herring seemed to be somewhat superior to haddock. Terroine (1933) reported the biological value of haddock flesh to match that of beef and milk. Flesh of cod was somewhat lower, but still exceeded the value for casein (see figures below). The nitrogen balance method of Thomas (1909) was employed in his study.

The biological values of these fish, as measured on man, were: haddock, 103; cod, 88; beef, 104; milk, 99; casein, 66. It is difficult to conceive why this difference was manifested between cod and haddock. In most later studies no basic differences have been observed between the proteins of these two fishes. Several such nitrogen balance studies are available on United States fish meals by Schneider (1932), on East Indian fish by Basu and De (1938), and salt-water and fresh-water (Bengal) fish by Basu and Gupta. Carere Comes (1936) compared fish flesh and beef as to their nutritive value and found them equivalent. Lanham and Lemon (1938) followed the growth of rats that had been fed either acid-extracted beef or fish protein at a 9% level for 10 weeks. The animals receiving fish protein grew better than those fed beef protein. A sample of red snapper protein, damaged in extraction, gave poor results. Correcting for differences in consumption, the various kinds of fish protein showed values of 80 to 90%, while that of beef protein was 63%, expressed in percentages of the nutritive value of oyster protein. In all cases the growth effects of protein from three Bengal fishes was superior to that of casein on 5 and 10% levels. On a 15% level, no differences were noted. The biological value of these three fishes differs somewhat, one species, "air," always being more efficient on a 5% level (Saha, 1940b). A high biological value for other East Indian fishes was also reported by Appanna and Devadatta (1942). Sekiné (1926a) compared in rat experiments the growth promoting effect of cherry salmon against that of the mollusk, *Tapes philippinarum,* and found the fish flesh superior—approximately 25% higher.

Beveridge (1947a) carried out growth investigations. Beef cuts roughly representing the entire steer, egg protein, and samples of ling cod, halibut, lemon sole, white spring salmon, herring, and red snapper were compared. Instead of the solvents being extracted, the samples were autoclaved, pressed, minced, dehydrated at 60°C. to a water content of 2 to 4%, ground to a meal, and incorporated into the diet of rats at a 8% level. After correction for varying food intakes, statistical analysis of the gain in weight per gram of ingested protein indicated that the values for fish protein were higher than those for beef or egg protein.

On a 12% level the protein efficiency ratio was 3.30 for halibut, 3.19 for beef, and 2.89 for casein.

Slightly different results were obtained by Nilson *et al.* (1947). Fish and beef samples containing, on the basis of the nitrogen content, 86–97% protein were prepared by thorough acetone extraction. This material was included in a basal diet at a 9% level along with 1.5% protein, derived from other such sources as yeast, wheat germ, and cornstarch. Although the rats that received the fish protein grew noticeably better than those that received the beef protein, adjustment for variation in consumption removed this difference. The presence of additional protein constituents may have modified the apparent nutritive properties of the protein being tested, and pair feeding experiments would probably have yielded more reliable results than the recalculation of data employed; nevertheless, these experiments demonstrate that fish protein is at least equal to beef protein in the promotion of growth in rats. In addition, by means of fecal nitrogen analyses, it was shown that the apparent digestibility of all of the proteins investigated was approximately the same and averaged 89.9%. Noteworthy is the fact that the seventeen fish species were approximately equal in their protein value. No difference was observed between marine and fresh-water fish.

Swordfish protein has also been shown to be equal or superior to beef or chicken protein at equivalent feed and protein intakes in promoting the growth of rats (López-Matas and Fellers, 1947). An overwhelming number of studies support and justify the conclusion that fish protein has a high biological value probably somewhat above that of beef.

A number of authors have reported that, on the basis of rat growth experiments, fish protein definitely has a greater nutritive value than casein, when measured in terms of growth. In the experiments conducted by Abderhalden (1936), for example, the body weight of 22 rats fed purified cod protein increased 121% during a 59-day period, while that of a group fed casein increased only 103%. Similar results were obtained by Saha (1940a) who compared Bengal fish protein and casein, as shown in the following tabulation:

Protein level %	Fish	Weight gain in experimental rats (5)
21	Mackerel	110
21	Casein	80
9	Tuna	30.5
9	Casein	8

Lanham and Lemon (1938) compared the efficacy of various proteins in promoting growth and obtained the following values (weight gain of white experimental mice per gram of protein): cod, 1.96; sardine, 2.03; mackerel, 2.23; beef, 1.64.

Deuel *et al.* (1946a, b) investigated some California fish (sardine, tuna, and mackerel) in this respect. At all protein levels these proteins were superior to casein, with a biological value on the average 50% higher, but certain differences were observed as to blood-regenerating capacity and hemoglobin production. At lower levels of protein intake, fish flour from Philippine "dilis" (see Section XI) gave a better growth response than casein (Alcaraz-Bayan and Leverton, 1957b). Costamaillere and Ballester (1956) showed that fish flour was as effective as whole milk powder in improving the growth rate of rats on a low-level diet. Fish protein was matched only by whole egg powder as to PER according to investigations by Chapman *et al.* (1959). Spanish investigations on two marine fishes (hake and croaker) arrived at similar results. Taking the net protein utilization of powdered egg as 100, the average value for fresh hake was 88.8 (Pujol and Varela, 1958). Fish flour was superior to casein in rat experiments on a 7 and 10% level and equivalent on a 15% level (Morrison and Campbell, 1960). An almost opposite finding was reported by Lindner *et al.* (1960). Carp protein was exceeded in biological value by casein and potato protein. Several fishmeal samples showed a protein value superior to that of nonfat milk solids and whole eggs (Nehring and Wünsche, 1959).

In feeding tests with prematurely born babies, freeze-dried fish powder as a protein supplement to the human milk was, as to growth curves, quite comparable to those for casein (Schäfer and Grüttner, 1957). Lean fish, furthermore, contains more protein per 100 calories than do dry milk solids. Nonfatty fishes, consequently, are excellent ingredients in protein-rich dietary prescriptions (Wenderoth, 1960).

Another interesting comparison was made possible by the recent commercial availability of canned, strained fish products which have been introduced as a result of the observation that fish is well tolerated and highly nutritious when included in the diet of infants. Using a low temperature and "freshly prepared dried skim milk product" as a standard, the nutritive properties of strained yellowfin tuna and other strained products such as beef, veal, pork, and lamb have been studied (El Rawi and Geiger, 1952). Both ad libitum and paired feeding experiments with infantile rats indicated that the average gain per gram of nitrogen consumed was in all instances greatest in the groups fed the skim milk, while the growth observed in the groups fed fish was somewhat greater than in those receiving the meat products. Equalization of the mineral and lactose contents of these protein sources did not eliminate these differences. Cod protein matched fully or even surpassed milk protein in infant feeding (Schäfer and Grüttner, 1957).

The protein efficiency ratio of canned Atlantic sardine was established as 2.8–2.9 in a recent experimental study with rats (Lanteaume *et al.*, 1959).

Due to the economical importance of poultry feeding, the nutritive value of fish protein in the feeding of chicken has also been thoroughly investigated. Almquist (1957) in an excellent review concluded that . . . "high quality fishmeal is a complete source of amino acids (for the chicken) . . . actually it is one of the few sources of protein that will support normal chick growth entirely by itself. Meat scrap tends to give a surplus of lysine and arginine but a deficiency in the sulfur amino acids and tryptophan. Milk proteins are known to be deficient in arginine for the chick but are good sources for lysine and tryptophan." (See further Chapter 9, Section IV.)

In addition to growth, body-weight and maintenance experiments, studies involving nitrogen balance techniques and the rate of restitution of blood proteins have confirmed the fact that fish contains protein of a high biological value. Deuel *et al.* (1946a) established that casein and fish protein were equally efficient in restoring plasma protein, but the latter were better with respect to the regeneration of hemoglobin. Studies on man (Wilson, 1949) and with dogs (Whipple and Robscheit-Robbins, 1926) support the contention that fish protein is not superior to casein with regard to the production of hemoglobin. In unpublished experiments, Geiger found that paired feeding of either beef or fish protein to protein-depleted rats resulted in almost identical rates of repletion. The more recent and expedient methods developed for the determination of the biological value of proteins as described by Allison (1955), Miller and Bender (1955) have only recently been extensively applied to the evaluation of fish protein. The net protein utilization (NPU) for a number of fish meals and fish flours ranged from 18 to 80 (Bender and Haizelden, 1957). There is a good possibility that such tests in the future may reveal small differences in the biological values of the various kinds of fish and that such differences may be of considerable theoretical importance. It is evident, however, that questions of price, taste, and availability will continue to be more decisive factors in the choice of high-grade fish protein for practical nutrition.

In summary, the nutritive value of fish proteins may be assessed in several ways: (a) the nitrogen balance method, using experimental rats, (b) employing liver enzymes from rats, (c) using xanthine oxidase, (d) using α-amino-oxidase, (e) study of changes in creatinine nitrogen in urine of rats, (f) the rat or chick growth method for determining availability of lysine, or (g) study of the growth of rice moth larvae.

V. Amino Acid Composition

In order to evaluate fully the nutritive value of fish protein, it is desirable to establish its amino acid composition. Those data that have been published during the past 30 years employing chemical, enzymic, microbiological, and chromatographic methods for the amino acid determinations have been compiled and reviewed by Geiger (1948), Block and Bolling (1951), and others. Many of these data were obtained without the benefit of the more recent technical improvements, and besides that, the method of amino acid determination as well as the sampling procedures and the method employed for the hydrolysis of the protein frequently were unsatisfactory. In addition, the values presented by different investigators are not strictly comparable, since the variable nonprotein nitrogen content of fish has in many cases not been considered in the calculation of the amount or proportion of amino acid present. These reasons probably account for the variation seen in the values tabulated in Table V.

TABLE V

THE AMINO ACID COMPOSITIONS OF THE FLESH OF FOUR BRITISH FOOD FISHES[a]

	Composition (grams/100 g. protein)			
Amino acid	Cod	Haddock	Lemon sole	Herring
Aspartic acid	10.64	11.61	11.80	10.95
Threonine	5.26[b]	5.79[b]	5.70[b]	5.34[b]
Serine	5.38[b]	6.11[b]	6.05[b]	5.63[b]
Glutamic acid	16.57	17.40	16.65	16.95
Proline	4.20	4.27	4.73	4.40
Glycine	5.08	5.20	5.00	5.06
Alanine	7.19	6.99	6.94	7.35
Valine	5.79	5.68	5.85	6.00
Methionine	2.07	3.22	3.42	2.02
Isoleucine	4.88	4.68	5.47	5.09
Leucine	9.31	9.31	8.70	9.59
Tyrosine	4.04	4.25	4.08	4.10
Phenylalanine	4.67	4.67	4.85	4.73
Lysine	10.32	11.02	10.73	10.29
Histidine	3.47	3.67	3.62	3.69
Arginine	6.74	6.99	6.76	7.33
Cystine/2	1.42	1.38	1.44	1.42
Tryptophan	1.32	1.43	1.56	1.41

[a] Source: Connell and Howgate (1959).

[b] Corrected for hydrolytic losses.

The only early data relating to the composition of fish muscles are furnished by hydrolysis of the muscle of halibut by Osborne and Heyl (1908) and by Okuda and Oyama (1916). These Japanese researchers compared their halibut findings with those of *Pagrus major*, one of the most common Japanese food fish. Broadly evaluated, these two species were quite similar. The following differences were, however, noted. *Pagrus* had higher contents of phenylalanine, but contained less proline and aspartic acid compared to the halibut. Major deviations were found in alanine and glutamic acid. More than 1% of the ash- and moisture-free flesh substance was constituted by alanine in *Pagrus*, while halibut contained only traces. Conversely, halibut was a very rich source of glutamic acid (10.1%) as against 1.6% for *Pagrus* (Okuda and Oyama, 1916).

Most studies agree that the amino acid pattern of fish protein closely approximates that found in any other class of animal protein (Osborne and Heyl, 1908; Beach *et al.*, 1943; Greenhut *et al.*, 1946, 1947, 1948; Ney et al., 1950; Joshi *et al.*, 1958; Lyman and Kuiken, 1949; Millares and Fellers; 1948; Stansby, 1953) (see Table VI). Dunn (1947) employed identical methods for the analysis of beef, pork, and fish protein, which clearly substantiated this view. This is to be expected since the edible portion of fish, beef, lamb, pork, chicken, turtle, frog, and many other animals consists principally of muscle tissue which is structurally and functionally of a similar nature.

Innumerable analyses of the amino acid composition of fish protein have been published since Geiger (1948) and Jacquot and Creac'h (1950) presented their reviews. Available major listings such as Harvey (1958), Orr and Watt (1958), and Love *et al.* (1959) are far from complete (see also Table VII). A few general conclusions can, nevertheless, be drawn from these figures.

The relative composition of fish proteins, although resembling that of mammalian meat, generally has lysine and histidine on a high level and occasionally methionine and tryptophan on the low side. Rosedale (1929) had previously underlined the fact that fish flesh differed from mammalian meat in its higher content of diamino nitrogen, chiefly these first two amino acids plus arginine. Lysine is frequently 30% above that of beef (Edwards *et al.*, 1946, and several others). Block and Bolling (1945) and Beach *et al.* (1943) maintain the lysine level to be approximately the same for beef and fish protein. A certain deficiency prevails in phenylalanine, isoleucine, and particularly methionine. This latter frequently shows high values (see p. 54). In most cases cystine, together with methionine, is the limiting acid, particularly in marine species. A few exceptions to this general rule will be discussed later (p. 55). On the

TABLE VI

AVERAGE AMINO ACID CONTENT OF FISH AND MEAT SAMPLES[a, b]

(Values given as per cent of protein, N × 6.25)

Amino acid	Atlantic mackerel (6)	Pacific mackerel (6)	Atlantic sardine (6)	Pacific sardine (8)	Atlantic[c] herring	Salmon (6)	Tuna (8)	Beef (2)	Whole ham (4)
Arginine	5.8	5.5	5.5	5.1	7.1	5.8	6.4	5.3	6.1
Histidine	3.8	5.4	2.4	4.7	1.9	2.6	3.5	5.7	3.6
Isoleucine	5.2	5.0	4.0	4.6	6.2	4.9	4.9	4.7	5.0
Leucine	7.2	7.4	7.1	7.2	7.1	7.3	7.9	7.2	7.8
Lysine	8.1	8.5	7.8	8.4	8.3	8.0	8.9	8.3	8.7
Methionine	2.7	2.8	2.7	2.8	2.6	3.0	2.5	2.8	2.7
Phenylalanine	3.5	3.8	3.4	3.7	3.6	3.7	3.8	3.5	3.8
Threonine	4.9	4.5	4.4	4.3	4.1	4.4	4.2	4.5	4.5
Tryptophan	1.0	1.0	0.8	1.0	0.8	0.9	1.0	1.0	1.0
Valine	5.4	5.2	5.0	5.2	5.4	5.6	5.4	5.1	5.2

[a] Sources: Neilands *et al.*, 1949; Dunn *et al.*, 1949.

[b] Figures in parentheses in column headings indicate number of samples.

[c] Data for Atlantic herring from Boge (1960).

TABLE VII

SELECTED REFERENCES TO REVIEWS ON AMINO ACID COMPOSITION OF FISH FLESH[a]

Continent, country, and type of fish	Reference
Africa	
Belgian Congo	
Katanga fishes	Baruh and Gillard, 1959
Asia	
India	
Salt-water fish	Venkataraman and Chari, 1957 Chari, 1957
Fresh-water fish	Airan and Master, 1953 Sarkar and Raha, 1954
Bombay fishes	Airan and Master, 1953 Kulkarni, 1953 Master and Magar, 1954 Valanju and Sohonie, 1957a, b Joshi *et al.*, 1958
Bengal Bay	Bose *et al.*, 1958
Indonesia	
Fresh-water fish	Dupont, 1958
Japan	
Pacific coast	Sugimura *et al.*, 1954 Matsuura *et al.*, 1954 Sekiné and Akiyama, 1926
Tuna	Kōnosu *et al.*, 1958
Malaya	
Singapore horse mackerel	Rosedale, 1929 Rosedale and Oliveiro, 1930
South America	
Brazil	
"Paiche" (Pirarucu)	Giral and Anza, 1951
Peru	Moreno, 1950 Hortencia Oliveros, 1951 Gallegos Villa, 1953 Morales Gallego, 1953 Injante La Rosa, 1954
Venezuela	Jaffé et *al.*, 1956
Europe	
Sardine	Dunn, 1947
Holland	de Man and Zwiep, 1955
Portugal	Gonçalves-Ferreira, 1952
Hungary	Lindner *et al.*, 1960
Poland	
Baltic cod	Dabrowski and Ganowiak, 1959
Spain	Pujol and Varela, 1958
Sweden	Ågren, 1944, 1949, 1951

[a] See also Table VI.

TABLE VII (*continued*)

Continent, country, and type of fish	Reference
North America	
Salt-water (Atlantic coast)	Teeri *et al.*, 1957
United States	
Alaska pollock	Landgraf, 1953
Trout	Block, 1959
Canada	
Mexico	
Miscellaneous	Cravioto *et al.*, 1953 Massieu *et al.*, 1954
Mexican carp	Villadelmar *et al.*, 1956–57

whole, it can be concluded that the structure of flesh proteins in different vertebrate animals, including that of fish, is essentially the same (Sarkar and Raha, 1954; Joshi *et al.*, 1958).

As pointed out by Deas and Tarr (1947), two one-pound loaves of bread prepared from flour furnish as much tyrosine as one pound of fish flesh; in tryptophan, three loaves are equivalent to this amount of fish, and five loaves are needed for a comparable amount of threonine. The greatest discrepancy occurs with regard to lysine. It would take eight loaves of bread to supply as much lysine as occurs in one pound of average fish flesh. Thus lysine is the chief limiting factor. Pound for pound, fish can be said to be eight times more valuable than bread in supplying this essential dietary factor. Fish flesh, however, almost completely lacks the carbohydrate constituents so characteristic of many foods of plant origin.

Ambe and Sohonie (1957c) established that shark and skate fish proteins in comparison to casein contained more basic amino nitrogen, while casein is richer in nonbasic amino acids. Therefore, one or more of the amino acids, arginine, histidine, lysine, and cystine, which go to form this fraction, must be present in larger amounts in the fish protein than in casein.

These two fish proteins were very rich in lysine, arginine, alanine, glutamic acid, threonine, and cystine. Casein was superior only with respect to phenylalanine, tyrosine, and proline. In a later study devoted to EAA, it was found that casein was superior to skate and shark protein in threonine and tryptophan, while these same fish proteins were superior to casein in arginine, isoleucine, and methionine (Masheklar and Sohonie, 1959). The differences in the concentrations of the amino acids in these two fish proteins are not so marked as to suggest a definite rating between the two. It may thus be concluded that both shark and skate are quite comparable, if not superior, to casein, as far as the amino acid composition is concerned, and consequently could readily serve as a cheap substitute in correcting the deficiencies of a number of essential amino acids, especially when the dietary proteins are poor in lysine, arginine, and cystine.

Complete analyses of fish flesh are few. The most comprehensive are those by Connell and Howgate (1959), Kōnosu *et al.* (1956), and Ito (1957). The British study covers such major European food fishes as cod, haddock, herring, and lemon sole. The Japanese paper covers corresponding food fishes from that country, such as the Pacific sardine, sockeye salmon, carp, Japanese horse mackerel, nine species altogether. Lindner *et al.* (1960) reported on the amino acids in the flesh of the common carp. Only one near-complete analysis of the amino acids in the flesh is available from earlier years (Ågren, 1944). His results, however, deviate markedly from more recent figures.

Fragmentary analyses are reported: three from cod (Abderhalden *et al.*, 1936; Neilands *et al.*, 1949; Beach *et al.*, 1943), three from haddock (Lahiry and Proctor, 1956; Edwards *et al.*, 1946; Proctor and Bhatia, 1950), and one on the Atlantic herring (Neilands *et al.*, 1949), but none for lemon sole appear to have been published. Such studies in print have been restricted mostly to one or several of the nutritionally important amino acids threonine, valine, methionine, cystine, isoleucine, leucine, phenylalanine, lysine, histidine, arginine, and tryptophan (e.g., Pottinger and Baldwin, 1946). On the whole, the figures from the study of Connell and Howgate (1959) are slightly higher than those in earlier publications—see further Table V. This is particularly true of threonine, leucine, phenylalanine, lysine, and histidine. These United Kingdom values agree well with the complete Japanese findings (Kōnosu *et al.*, 1956). Two exceptions are for histidine, where the Japanese results are lower, and aspartic acid, where the rather variable content of this amino acid found in the Japanese species is not apparent in the British values. Carp appears to be low in threonine and phenylalanine (Petrenko and Karasikova, 1957).

The amino acid composition of the flesh of wild and cultivated trout varies only slightly under the influence of different natural and artificial diets (Block, 1959). Preliminary findings on the synthesis of the muscle protein from amino acids in the feed such as chironomids, the cladocers, (*Daphnia*), and various presscakes were reported by Petrenko and Karasikova (1957).

As a whole, fish proteins from different species seem to vary insignificantly (Connell and Howgate, 1959). In other words, fish muscle proteins are relatively uniform (Matsuura *et al.*, 1955; Kōnosu *et al.*, 1956). This can be extended to include even such major groups as teleosts and elasmobranchs, as well as salt-water and fresh-water fish (Winter, 1949; Kōnosu *et al.*, 1956). Fresh-water fish exhibit excellent aminograms. Several such studies show this. Indonesian, Indian, and German species have all been studied in this respect. Particularly superior nutritive value was shown by lake perch (Winter, 1949). Other species analyzed—all with good quality protein—were ruff, roach, and white beam. The protein of young perch carries a high amount of hexene bases (Winter, 1949). The contrast to the figures referred to above may be attributable to better methods of analysis now available, a better recognition of the changes taking place in amino acids already in early stages of spoilage, and to a more accurate distinction experimentally drawn between the free amino acids and the true proteins.

One essential feature seems to be the comparatively high amount of α-amino nitrogen (65–75%) actually built into the fish protein molecules. This is apparent in European, as well as East Indian, species (Valanju and Sohonie, 1957a-d).

A few particularly interesting cases may be mentioned. The Indian pomfret ranks high in its over-all aminogram (Venkataraman and Chari, 1957). This is also the case with the agile Amazon species *Arapaima gigas* (Hortencia Oliveros, 1951). Sekiné (1921, 1926b) reported basic differences in the amino acid composition of flesh protein in the male and female of six species. Arginine, histidine, and cystine decrease, and lysine becomes more abundant during build-up for spawning. It is suggested that this is explained by the conversion of arginine and histidine into nuclear compounds. The protein in the male is richer in lysine and arginine, but poorer in histidine as compared to the protein in the female.

If the amino acid composition of fish proteins shows few distinctive features, this is likewise true of their pool of free amino acids. The constituents of this pool appear rather uniform, but the relative amounts of individual amino acids show characteristics specific for almost each fish species (Duchâteau and Florkin, 1954, 1957) (see also p. 59).

The aminogram differences between red and white meat are minor but, surprisingly enough, they are consistent and identical in all species studied so far. It is noteworthy that the red meat of fish is closer to the red meat of terrestrial animals than is the white flesh of fishes. Glycine, leucine, phenylalanine, and arginine are higher in red meat, while lysine, aspartic and glutamic acids dominate in ordinary white meat (Matsuura *et al.*, 1955) (see further Section VII). Earlier investigations by Sekiné (1926b) show that red meat ("chiai") contains more histidine and less lysine, arginine, and cystine.

Indications are that the aminogram of the muscle changes during spawning. At any rate, the amino acid content, in terms of arginine, histidine, methionine, tryptophan, and tyrosine, varies for muscle and gonads of male and female Baltic herring at different stages of growth (Petrenko and Karasikova, 1958). In female fish, as the ovaries matured, the arginine content of muscle fell from 10 to 4.5% of the crude protein; methionine and tryptophan were considerably reduced, but tyrosine only slightly. In young male fish muscle, arginine and histidine rose, while tyrosine fell from 4.2 to 2.9% as the gonads ripened. In the male gonads, changes in arginine, histidine, and methionine were small, but tryptophan and tyrosine fell sharply from 5.6 to 1.4 and from 6.2 to 0.7% of the crude protein, respectively. In previous studies C. W. Greene (1919) and C. H. Greene (1919) found that the protein content of spring salmon muscle tissue dropped from 20.1 to 14.0%. A similar decline in these protein fractions was observed by Duncan and Tarr (1958). Tarr (1959) also reported in general a depletion of protein during the spawning of sockeye salmon, somewhat more accentuated in female specimens than in males.

A. Essential Amino Acids (EAA)

Various types of fish protein have been analyzed for the content of EAA in desirable concentrations for human beings. Several researchers (Pottinger and Baldwin, 1940, 1946; Beach *et al.*, 1943; Block and Bolling, 1945; Deas and Tarr, 1949; Dunn *et al.*, 1949; Neilands *et al.*, 1949; Gonçalves Ferreira, 1952; Kulkarni, 1953; Edwards *et al.*, 1955; Matsuura *et al.*, 1955; and Sanahuja and Seoane Rios, 1955–56) studied the amino acid make-up of fish and found that fish and fish products provide protein of the finest nutritive quality, when evaluated on the basis of its content of EAA (Table VIII). Kraut (1957) studied the quantities normally carried in a serving of 200 g. of white fish (see Table IX). Lysine, threonine, isoleucine, leucine, and valine are in excess, while tryptophan, phenylalanine, and methionine are below the optimum amount and in the order listed.

Japanese workers (Kōnosu *et al.*, 1956) found that the content of EAA in shark protein is much the same as in teleost fish. As noted previously, the concentration of essential amino acids in protein of shark and skate caught in Indian waters was superior to the corresponding figure for casein. This suggests the value of these fish proteins as a supplement to deficient protein diets (Ambe and Sohonie, 1957c). Both sharks and teleosts from the Bengal Bay constitute good sources of EAA, with the exception of Bombay duck, which lacks methionine (Bose *et al.*, 1958).

When the fish aminogram is compared to that of hen's egg protein,

TABLE VIII
ESSENTIAL AMINO ACID CONTENT OF RAW FISH MUSCLE[a, b]

Amino acid	Shad	Haddock	Pomfret	Beef muscle
Lysine	9.8	8.6	10.8	8.7
Arginine	5.7	5.7	5.4	6.1
Histidine	2.3	1.9	1.9	3.6
Leucine	7.7	7.5	7.3	7.8
Isoleucine	5.0	5.4	5.0	5.0
Valine	6.2	5.6	4.0	5.2
Threonine	4.1	4.2	4.4	4.5
Methionine	2.8	2.8	2.6	2.7
Phenylalanine	3.7	3.7	3.2	3.8
Tryptophan	1.1	0.9	0.9	1.0

[a] Source: Lahiry and Proctor (1956).

[b] The amino acid values are given as gram amino acid yielded by 100 g. of anhydrous ash-free protein.

TABLE IX
DAILY AMINO ACID REQUIREMENTS MET THROUGH FISH SERVING[a]

Amino acid	Daily requirement of 150-lb. man (grams)	Amount in 200 g. fish fillet (grams)	Percentage covered when consuming 200 g. fish fillet
Threonine	1.0	1.6	160
Valine	1.6	2.0	125
Leucine	2.2	2.8	125
Isoleucine	1.4	2.0	140
Lysine	1.6	3.2	200
Methionine	2.2	1.2	55
Phenylalanine	2.2	1.4	65
Tryptophan	0.5	0.4	65

[a] Source: Kraut (1957).

histidine and lysine generally occur in excess, while tryptophan is markedly low in fish protein (Saraiva de Costa, 1956).

The fermented fish sauce of the type nuoc-mam also constitutes a good source of EAA (Nguyen-thi-lai, 1959), except of histamine which is almost completely absent. The Vietnamese have from this source a daily intake of 1.2 to 2.4 g. of nitrogen, depending on the social class. Most of this nitrogen is in the form of amino acids and polypeptides (see further Chapter 20, Volume III).

B. SULFUR-CONTAINING AMINO ACIDS

1. *General*

More than 1% of the total dry matter of fish flesh consists of sulfur, according to the findings of Airan and Master (1953) on eight samples belonging to three major families. With one exception, there were more cystine than methionine. This contrasts with the findings of Nakae (1942) and Tsuchiya (1944), who, working independently, found appreciably more methionine than cystine. Tsuchiya furthermore reports a consistently high level of methionine in eight species studied (5.5–17.9%). Nakae (1942) found that the cystine content was rather stable (0.4–1.2%), but the methionine varied a great deal (0.7–14.7%). Several East Indian fresh-water food fishes have been analyzed with reference to cystine and methionine (Airan, 1951; Airan and Powar, 1952). The pike perch contains appreciably more methionine and cystine than beef (Sharpenak *et al.*, 1937). The sulfur distribution in fish flesh protein was particularly studied by Beveridge (1947b). A recent Spanish study has investigated the distribution of sulfur amino acid in fishes of the perch family (Rodríguez Rebollo, 1959).

2. *Methionine*

A Soviet study of the amount of methionine in various fish proteins found major differences between species, sufficient to justify specific recommendations in this respect for their use in dietary (antifat) planning (Gorozhankina, 1955), but further investigations are required. Earlier Soviet investigations found methionine highest in fish among all major foods (Sharpenak and Eremim, 1935).

Japanese studies generally give methionine in the range of 2.0 to 3.9% of the proteins (Tsuchiya, 1944; Ogata, 1951–52; Hatakoshi, 1953), while Soviet investigation figures range from 1.6 to 2.3% (Gorozhankina, 1955). Love's table gives values of 0.7–3.7, the low figures being for swordfish. High values (3.6–3.9%) were reported in analyses of Peruvian marine fishes (Pallardel Peralta, 1951; García Terry, 1952; Injante La Rosa, 1954) as well as fresh-water species (Hortencia Oliveros, 1951). The latter attain 4.2–3.4 g./100 g. of protein. East Indian studies show a lower methionine content than in most other fishes. It was not even present in the muscle tissues of the Indian marine fish Bombay duck (Venkataraman and Chari, 1957; Bose *et al.*, 1958). It is also reported low in United States marine fishes (Teeri *et al.*, 1957).

Herring meal is particularly high in methionine (Nehring and Schwerdtfeger, 1957). In this case, comparison was made with cod, analyzed for methionine by Abderhalden (1936). On the other hand, there are several indications that heat-damaged meal may be low in methionine, this acid becoming limiting.

Schormüller and Ballschmieter (1951) claim that fresh-water fish are particularly potent in methionine. This might depend on the proportionately higher amount of sulfur encountered in fresh-water fish (see further Chapter 8, Volume I). On the other hand, Sas (1953) in Chile, found that the albumin of carp was lower in methionine (0.585%) as compared to stockfish and flounder (0.71%).

Some difficulties of the reliability of the methods used for determining methionine are pointed out by Connell and Howgate (1959). They analyzed four common British food fishes; cod, haddock, lemon sole, and herring, as to methionine, comparing chromatographic and chemical analytical methods.

3. *Cystine*

In fish protein, cystine is four times more abundant than in casein (Ambe and Sohonie, 1957a). Other East Indian fishes were analyzed for cystine without comparing with casein (Mahadevan, 1950). This conclusion is based on chromatographic analyses of protein from sharks and skates. In most other fishes from other geographical regions it is frequently low (Teeri *et al.*, 1957). This was also true in two food fishes from Bombay (Kulkarni, 1953). Taranova *et al.* (1955) found fish protein slightly richer than terrestrial meat proteins in this amino acid. In freshly prepared muscle tissue of carp and eel, cysteine is nine times more prevalent than cystine. This contrasts with egg albumin, where cystine occurs in much greater quantities than cysteine (Okuda and Katai, 1931).

C. TRYPTOPHAN

In most fishes, tryptophan content is on the low side. This is stated as a common characteristic of Scandinavian fish meals (Nordfeldt, 1952). Indian investigators even maintain that this amino acid is completely lacking in fishes belonging to the sardine group, e.g., the Indian sardine and the oil sardine (Venkataraman and Chari, 1957). It seems less likely that any fish could entirely lack tryptophan, since fish myosins studied so far resemble each other greatly and contain this amino acid. It is therefore conceivable that the low content of tryptophan could be explained by the susceptibility of this amino acid particularly to browning reactions in the preparation of samples. In fourteen marine Peruvian fish tryptophan content ranged from 0.128 to 0.350 mg./100 g., when calculated on a fresh-weight basis (Sanchez Moreno, 1950). Very low values are also reported in fish from Angola (Saraiva da Costa, 1956). In Pacific sardine, rayfish, and plaice, Japanese studies indicate that tryptophan content ranged from 1.36 to 1.83% on a moisture-free basis (Iwamura and Yamoda, 1950–51).

In a recent critical study, Kōnosu and Matsuura (1960) reported that consistently higher tryptophan values were obtained with the microbiological method after hydrolysis with barium hydroxide, than with the sodium hydroxide ingestion method. The amount of tryptophan in raw fish flesh ranged from 1.25 to 1.35%, and variation among the species of fish was quite small. Tryptophan content in canned and salt-dried fish meats was almost at the same level as that in raw meat. It was also found that the tryptophan content in muscle protein, on the other hand, was considerably higher than that in flesh from which it was prepared. According to Kōnosu and Matsuura this may be explained by the loss of nonprotein nitrogen in extracting the protein for analysis. These tryptophan values are higher than the average value (0.99%) given by Orr and Watt (1957). Half of these latter data was derived from the two studies by Neilands *et al.* (1949) and Dunn *et al.* (1949); altogether eighty values were given for Atlantic and Pacific mackerel, Atlantic and Pacific sardine, cod, salmon, and tuna.

This particular amino acid seems to be lower in the flesh of most fishes than in meat of terrestrial animals, at least under Argentine conditions (Sanahuja, 1955) given in the following figures: pork, 0.805–0.838%; beef, 0.715–0.835%; fish, 0.346–0.680%. Whale meat shows a proportionately higher content of tryptophan than fish (see Section XV). The flesh of pike perch exceeds beef in the amount of tryptophan (Sharpenak *et al.*, 1934); similar findings from fresh-water fishes are reported by other Soviet investigators (Taranova *et al.*, 1955) and by Schormüller (1950).

D. Lysine

Lysine appears to be ample in fish flesh protein, frequently exceeding that found in other animal proteins (Teeri *et al.*, 1957). Fish generally is a more potent source of lysine than egg protein and approximately eight times more potent in lysine than bread (Deas and Tarr, 1947). The superior PER values for fish flour can be attributed to their abundance of lysine (Morrison and Campbell, 1960); consequently, this product constitutes an excellent supplement to bread and flour. The aminogram proves that shark and skate protein is superior to casein with respect to this amino acid.

Lysine accumulates in fish flesh during spawning and generally is higher in males than females. Six major species were studied (Sekiné, 1921, 1926b).

Fish meal from ocean perch is particularly rich in lysine (Nehring and Schwerdtfeger, 1957). It has been experimentally established in human beings that the availability of lysine is good in fish flour (Gupta *et al.*, 1958). This is also true of dried fish autolyzate (Adrian *et al.*, 1956).

Lea *et al.* (1960) suggested that when herring meal is overheated, available lysine is reduced through the protein being subject to the reacting effect of fat oxidation products.

E. Histidine

The occurrence of histidine and the risks of this being a precursor to the bacterial formation of histamine is analyzed in Chapter 10 of Volume I. Several red-meat fishes are undoubtedly potent sources of histidine. The protein of the fresh-water fish white bream shows a high level of histidine (Winter, 1949). On the other hand, Airan and Powar (1952) found wide variations as to Indian fresh-water fishes; some high (*Macrones singhala*), others low (*Muraena tile*). Peruvian marine fish show values ranging from 1.03 to 0.39% of the flesh tissue (Pallardel Peralta, 1951; Injante La Rosa, 1954). Singapore fishes showed, in general, a high content of histidine (Rosedale, 1929). Taranova *et al.* (1955) maintain that in general, fish proteins contain less histidine than do meat proteins. Yudaev (1950) found that the fresh-water fish perch and carp both contained large amounts of histidine, but no dipeptides. Despite this finding, it has been established that histidine does not arise from a hydrolysis of dipeptides. Histidine content in fish flesh drops during spawning (see p. 52). Protein in female frequently is higher than that in male tissue in this respect (Sekiné, 1921).

F. Leucine

Although leucine is generally high in fish protein (Teeri *et al.*, 1957), it shows relatively low values for Indian shark, silverbelly, and sole. In other Indian species the leucine content varies greatly (Master and Magar, 1954; Venkataraman and Chari, 1957).

G. Tyrosine

Several Peruvian marine fishes show a fair amount of tyrosine in their protein—0.31–0.77% on a fresh-weight basis (Sánchez-Moreno, 1950). Fresh-water species show higher values, 2.0–3.6 g./100 g. protein. Pike perch shows a higher amount of tyrosine than beef (Sharpenak *et al.*, 1934). On the other hand, the protein of sharks and skates contains less tyrosine than casein.

Tyrosine appears as whitish blemishes on the product surface in a crystallized form after extended proteolysis of herring semipreserves (Borgstrom, 1953), fish pastes (Burrell, 1948) and caviar (Patron *et al.*, 1950). This phenomenon sometimes has been mistakenly taken as mold growth. König and Grossfeld (1913) investigated in particular the special nature of caviar proteins and found them rich in ichthulin—in turn carrying tyrosine as a prevailing amino acid.

H. Arginine

Arginine is twice as prevalent in shark and skate protein as in casein (Ambe and Sohonie, 1957a). The prevalence of arginine was also established in two Indian teleosts ("ghol" and "mandeli") by Valanju and Sohonie (1957b). Several Argentine fishes have been analyzed. High values (5.9–5.8%) were reported for the Atlantic mackerel and the South American hake (*Merluccius gayi* Guich) by Sanahuja and Seoane Rios (1956).

In Baltic herring, as mentioned in Section V, the arginine, as well as the methionine and tryptophan, content of muscle protein drops appreciably as the ovaries mature (Petrenko and Karasikova, 1958). If this is true in most fish, the matter becomes complicated.

The arginine content of fish flesh is reduced during spawning (see p. 52).

I. Threonine

Threonine is now and then indicated as being in short supply in the flesh of various fishes. It has been specially studied in Japanese fishes and is available therein in adequate quantities (Hatakoshi, 1953): 2.9–3.9% of total protein. Both marine and fresh-water fish are good sources.

J. Phenylalanine

The range in Argentine fishes was given as 2.9–4.2% by Sanahuja and Seoane Rios (1956). Baertich (1950) reported 5.1% of this acid. Subsequent analyses fall in the same range—see tables in this chapter, as well as Block and Bolling (1945, 1951). Frequently quoted are the high values found by Ågren (1944). Doubt has been expressed as to their validity (Baertich, 1950; Connell and Howgate, 1959).

K. Valine

This constitutes a limiting factor in Mexican carp—almost 30% below the value for hen's egg protein (Villadelmar *et al.*, 1956–57). It is also low in the Mexican "pescado blanco" (*Chirostoma ester* Jordan) (Luz Suárez *et al.*, 1954).

L. Free Amino Acids

The conception of nonprotein amino acids as a pool has become clearer in latter years, chiefly due to chromatographical techniques which allow a clear distinction between this group of exogenous amino acids, and those which are protein-bound (Kühnau, 1949; Bigwood, 1953; Dabrowski and Ganowiak, 1959). The biochemical aspects of their function and appearance are fully discussed in Chapter 11, Volume I, by Simidu. Frequently, in nutritional studies the role of exogenic amino acids is not clearly conceived. In experiments with fish flesh, nutritive effects are commonly attributed to fish protein, overlooking the possibility that the free amino acids may add to the total effect and thus be a decisive element in the final judgment as to merits of one fish over another.

From this point of view, it is essential to be cognizant of the variation that does pertain to this pool of amino acids. Its increase through proteolysis is less important than the variation due to environmental factors and the breakdown by bacterial attack (Hughes, 1959). In herring, taurine and histidine are quantitatively the prevalent compounds. Taurine appears to be resistant to bacterial activity, but histidine may be converted into histamine. Most free amino acids increase during the spoilage—very much dominated by proteolysis. Lysine and serine show a drop. These changes need to be studied as to their nutritive effects. It is not sufficient to establish the biochemical spoilage pattern with respect to time. At any rate, it appears feasible to characterize fish quality as reflected in spoilage through the absolute and relative amount of free amino acids (Bramstedt and Worzbacher, 1960). The gradual appearance of tyrosine crystals on various fish products is discussed in Section V, G.

Each species appears to have a characteristic basic composition of its pool (Duchâteau and Florkin, 1954, 1957). Histidine is a unique constituent which is entirely absent in most other animals, but quite high in carp (Yudaev, 1950; Duchâteau and Florkin, 1954), lamprey (Duchâteau and Florkin, 1957), and the herring-mackerel-tuna group (Shewan, 1955). In this latter case, histamine appears during the initial spoilage. This was confirmed for the herring by Hughes (1959).

Certain peculiarities were observed in the distribution of the dipeptides carnosine and anserine as well as of amino acids and glutamine in different fish groups inhabiting the Black and White seas (Severin and Vulfson, 1959). The muscle tissue of some species is devoid of carnosine and anserine, but contains amino acids of which they are composed: β-alanine in the skate muscles and histidine amounting to 0.8 to 3.0% on a net weight basis in the muscles of the pelagic group of teleosteans. In sturgeon flesh, carnosine and β-alanine have been detected; anserine and β-alanine occur in the skeletal muscles of the gadids, and in the salmonids anserine and histidine were found. Among the percids no dipeptides were found in the muscles, few amino acids, but large amounts of glutamine (90–200 mg.%). In the muscle tissue of fish caught in the White Sea, great amounts of glycine (70–115 mg.%) and of α-alanine (60–70 mg.%) were found.

Paper chromatographic studies of Indian fish revealed the presence of seven EAA appearing as exogenic, but no proline (Valanju and Sohonie, 1954). They undoubtedly play an important supplementing role and may radically change the nutritive rating of individual fish proteins.

Minor differences prevail between spawning fish and migrating fasting fish. The ascending lamprey has, on the whole, the same relative amounts of free amino acids as the fasting, descending specimen. The lamprey flesh is characterized by a high content of free histidine, glutamic acid, and glycine, the amounts of which correspond to the order given. Farris (1958) reported, however, that California sardines fed a balanced, complete diet showed a reduction in the amount of free amino acids. Better growth conditions reduced the free amino acids and both alanine and aspartic acid almost disappeared.

Duncan and Tarr (1958) reported a significant increase in the percentage of nitrogen in the nonprotein fraction of spawning spring salmon owing to a decrease in the total nitrogen of the samples. The actual composition of the fraction itself in terms of milligrams of nitrogen remained constant.

There seem to be certain regular seasonal variations in the free amino acid pool, particularly of glycine, glutamic acid, and taurine (Jones, 1959a). Jones (1955) established the presence of zinc-ion-activated anserinase, which triggers the release of L-methylhistidine and β-alanine prior to any bacterial invasion of the tissue.

Free amino acids, together with other nitrogenous extractives and certain volatiles, affect flavor. This amount, as well as that of free sugars, determines susceptibility to browning (Jones, 1959b), which may have a detrimental effect on the nutritive value. Part of these free amino acids may be due to proteolytic breakdown in spoilage or curing processing—see further Section IX, B.

Nutritionally important is the finding by Baertich (1950) that the relative amounts of the exogenic amino acids in fish flesh closely resemble those of human serum albumin. This might explain the remarkable efficiency of fish flesh in curing protein deficiency diseases (Baertich, 1950). In several cases the amount of such exogenic acids reaches 67.6% of the total nitrogen.

It is surprising that the fermented fish product nuoc-mam showed no peptides in chromatographic analyses, despite its proteolytic nature. An appreciable number of the amino acids commonly found in fish were identified, with the exception of histidine (Blass and Richard, 1952). In addition, two or possibly three amino acids characteristic for bacteria were found (Toury *et al.*, 1958).

Also, in Scandinavian semipreserves of herring and sprat ("anchovies") a gradual proteolytic breakdown takes place. Several free amino acids appear in the brine (Borgstrom, 1950, 1953; Alm, 1956) (see also Chapter 13, Vol. III). Presumably, these products play an important supplemental role in an extreme bread and porridge diet. This is also the nutritional significance of the fermented fish products of southeast Asia (Rose, 1959).

M. PROTAMINES

Other important sources of amino acids are the natural protamines. These are discussed in detail in Chapter 11 by Simidu in Volume I. Salmine and clupeine are the two best studied protamines (Block *et al.*, 1949). Salmine contains seven amino acids (Corfield and Robson, 1953; Phillips, 1955; Callanan *et al.*, 1957). The ratios of the seven amino acids occurring in the salmine molecule are arginine (34); proline (4); serine (4); valine (3); glycine (3); alanine (1); and isoleucine (1). The molecular weight of this compound has been calculated from analytical data as 7000 (Velick and Udenfriend, 1951). There seem to be only minor deviations as to the amino acid sequence between species. Using ion-exchange chromatography, this was reported to be true for the Pacific sardine and chum salmon (Ando *et al.*, 1959). On the other hand, it appears evident that most protamines are heterogeneous and cannot be defined as one single compound. The composition of clupeine is influenced by the spawning maturation of the gonads (Waldschmidt-Leitz and Gudernatsch, 1957).

The relative distribution of amino acids in salmon roe was generally uniform, being significantly altered only by maturity. Most of the amino acids are present in growing quantities with increasing maturity. The arginine and tryptophan levels proved quite constant, however, whereas the threonine content decreased with maturity. These trends were much more noticeable during the most immature stages of the roe. The essential amino acid content of salmon roe is found to be very similar to that for beef liver and pink salmon viscera (a hatchery fish feed) (Seagran *et al.*, 1954).

In milt of herring, salmon, etc., the amount of arginine is excessive, while lysine is frequently below normal.

N. OTHER FISH PRODUCTS

Fish scales, partially built by protein, are surprisingly well equipped with amino acids (Solomons, 1955; Burley and Solomons, 1957; Snyder, 1958). Besides collagen, other proteins are present. Hydroxyproline is an important ingredient in fish collagen, pike being richer than cod (Gustavson, 1955). On the basis of analysis of four species of fish commonly used for the manufacturing of gelatin, Eastoe (1957) concluded that the amino acid distribution was quite similar to that of mammalian collagen, but with smaller amounts of proline and hydroxyproline and higher values for serine, threonine, and, in some cases, for methionine and hydroxylysine. Variations in the properties and composition of fish collagens seem to be related to the water temperature of the normal habitat rather than fixed as a species characteristic.

Variations in the properties and composition of fish collagens seem to be more related to the water temperature, than to be of an intrinsic genetical nature (Eastoe, 1957).

The pyloric coeca of most fishes are sources of large amounts of amino acids. Efforts are being made particularly by the Japanese to utilize these sources for the commercial manufacture of various amino acids, primarily for dietary supplements.

Skins, eyes, and other body parts are important food items in many parts of the world. Few analyses are available as to their amino acid composition and as to variations between species, capture locations and seasons. The eye lens proteins of some Brazilian fishes were analyzed chromatographically and revealed a rather complete outfit of amino acids (Panek and Carvalho, 1955). Collagens are essential constituents of the skin tissue.

There is a growing trend—see Chapter 19, this volume—to utilize the livers of fish not only as a source of vitamins and other organic compounds but as food. Little is known as to their protein composition and variations in this respect. Hydrolyzates suitable for industrial therapeutic uses were manufactured experimentally by Guttmann (1955). The high nutritive value of fish viscera has been confirmed by several investigators (Salgado, 1953; McLeod, 1955) and constitutes a challenge to food technology.

VI. Dark Meat (Cat Food)

Most of the preceding feeding experiments were carried out with white-fleshed fish or the edible light meat of other varieties. In some fish (for instance, the tuna), the red or dark meat may represent about one-sixth of the total meat. For several years a considerable amount of this red meat has been utilized for the manufacture of pet food, primarily for cats. Several authors recently warned, however, that prolonged consumption of canned red meat may lead to pathological symptoms in cats. It seems imperative, therefore, to determine the nutritive values of this red meat. In controlled experiments Geiger compared the growth-promoting value of light and dark meat derived from precooked yellowfin tuna, but failed to publish his findings. Both kinds of meat were fed to rats at an 8 and 12% protein level for a 4-week period, and no difference in growth was found, when compared with rats on a good stock diet. He also found that white and dark meat had equal biological value when fed to previously protein-depleted animals as the only protein source during the repletion period. This merits further investigation since the higher content of myoglobin in red meat together with a higher ratio of connective and vascular tissue in red meat would seem to render a meat somewhat inferior to white meat as to the protein quality.

Recent investigations also indicate that the amino acid composition of dark meat is very similar to that of light meat. These investigations prove, therefore, that red meat represents a good source of nutritionally valuable protein. Minor differences could, however, be detected. According to Matsuura *et al.* (1955), the acids given in the tabulation below occur in somewhat larger quantities in white or dark meat, respectively.

PREVAILING AMINO ACIDS

White meat	Red meat
Aspartic acid	Glycine
Glutamic acid	Leucine
Histidine	Phenylalanine
Lysine	Proline[a]
Valine[a]	
Serine[a]	
Threonine[a]	
Methionine[a]	
Tyrosine[a]	

[a] In most cases.

The pathological findings observed after prolonged exclusive feeding of canned red meat to cats seem to be due to the lack of tocopherol (vitamin E) (Cordy, 1954), and inadequate amounts of essential fatty acids. The presence of polyunsaturated fish oils may aggravate these symptoms. The senior author, as well as Cordy and Stillinger (1953), found in long-term experiments with kittens that red meat supports growth well when tocopherol and fatty acids are fed simultaneously. After 16 weeks feeding, no steatitis or microscopic liver damage was observed. The bone structure and the hematological findings did not indicate any pathological changes.

Other investigations have rather stressed the detrimental effect of excess amount of unsaturated fatty acids not compensated by added quantities of tocopherol. Fish fed as a protein source should not contain more than 3–4% fat and the tocopherol values should be such to render full protection (Dalgaard-Mikkelsen *et al.*, 1958). In summer when fish show particularly high amount of polyunsaturated acids either the tocopherol amount in the feed will have to be augmented or restrictions be introduced in the use of fish as food (Dalgaard-Mikkelsen, 1953).

In conclusion, it is nevertheless evident that red or dark meat of fish, as well as white meat, represents a good source of protein with high nutritional value. Eventual difficulties ensue from the adjoining fats. They also show that in long-term feeding the supply of other essential nutrients, such as vitamins, essential fatty acids, and others should not be neglected. A special problem, however, is the fact that several raw fish carry an antithiamine factor (Cordy, 1954) which can be counteracted either by cooking the meat or injecting thiamine (Smith and Proutt, 1944; Scott, 1957) (see further Chapter 13 in Volume I).

The amino acid composition of tuna myoglobin (Mb) and hemoglobin (Hb) was determined by Kōnosu *et al.* (1958). Their compositions were compared with mammalian pigments. Differences between tuna and terrestrial animals, including man, were mostly of a quantitative nature. No differences were registered for leucine, methionine, and histidine. Among monoamino-monocarboxylic amino acids, alanine is most prevalent in tuna, as compared to leucine in mammals. Tuna Mb contains one cysteine residue, the absence of which has been reported for mammalian Mb's. In tuna Mb, glutamic acid and basic amino acids are low. In many respects, tuna Mb more resembles Hb than Mb in mammals. Similar findings were reported by de Marco and Antonini (1958). The species specificity of myoglobin from different fishes was investigated by Kendrew *et al.*, (1954).

Recent Italian findings furthermore indicate that fish myoglobin contains three fractions (Rossi-Fanelli and Antonini, 1956).

VII. Role of Minerals

Proteins have been linked to the mineral metabolism of fish in several ways. For several minerals this relationship was thought to be so firmly built into the metabolism that definite coefficients were elaborated. Statements of content of essential minerals were computed merely on the basis of analytical figures for protein content (Scherman, 1937). The justification for such a procedure has recently been reinvestigated by Soviet scientists on five major species of food fish (Vasilieva *et al.*, 1961). They found such a fixed ratio usually to be true for magnesium and phosphorus, not equally reliable for potassium calcium and iron, but valid in more than half of the cases with calcium.

There are certain indications that calcium resorption in the human body is interrelated with proteins, particularly those of animal origin (Lehmann and Pollak, 1942). It has been suggested that this depends on the binding capacity of lysine (Lehnartz, 1947; Baertich, 1950). McCance *et al.* (1942) showed that calcium is better resorbed in the presence of milk protein. Polyvalent ions such as calcium readily form complexes with several organic compounds, among them protein (Gubler and Schmidt, 1945).

The disturbances involved in protein deficiency frequently reduce the calcium resorption by one-third (Jones, 1936). This in turn causes a deprivation of calcium from the skeleton. Whether calcium shortage also increases the susceptibility to cancer is still an unsettled matter (Eichler, 1946) but a lead yet worth pursuing.

These general relationships do not appear to be specifically connected with fish, but apply generally to proteins. But from entirely other sources comes evidence linking the fish protein with specific minerals. Poultry feed devoid of fish protein gave significant growth responses when supplemented with zinc. Like results failed to materialize when identical rations contained fish protein. This raises the possibility that zinc is part of the fish protein and eventually constitutes part of the so-called unidentified growth factors (Klussendorf and Pensack, 1958).

VIII. Digestibility

The question of whether only free amino acids as such can be absorbed or whether there is also a significant absorption of amino acids in peptide linkages is still under investigation. It is generally agreed, however, that the absorption and subsequent utilization of a protein depends upon the ease and completeness with which the digestive enzymes are able to split the protein into single amino acids, i.e., its digestibility. Because the digestive enzymes are highly specific in their action and cleave only certain linkages, digestibility depends upon the nature of the linkages that exist between the individual amino acids and adjacent amino acid chains within the protein. As discussed in the next section, the digestibility of fish protein may be decreased by storage and certain other treatments by the creation of additional linkages.

Fish has been considered to be an easily digestible food for centuries. In many diseases doctors have recommended lean fish in preference to butcher's meat or even white chicken meat because it is thought to be more digestible. Fat fish, fish dishes prepared with fat or heavy gravies, or fried fish may produce a sensation of fullness, but this is a result of prolonged stay in the stomach, the gastric emptying being slower rather than lower digestibility.

Digestibility is not always clearly defined, whether meaning rate of digestion, rate of disappearance from the gastric tract, or amount of digestible matter. The effect of accompanying compounds, such as fats, spices, etc., is frequently ill-defined. It is generally measured in terms of proteolytic breakdown and its final step of amino acids, not accounting for intermediary polypeptides.

The statement made by Drummond (1918) that many of the chief food fishes are digested with difficulty, "either because of the presence of high fat or because of the coarseness of the fibers," is unsupported. Contrasting with this assertion is the observation by Davis (1912) that

3⅓ oz. of boiled salmon is delivered to the intestines from the stomach only after 3 to 4 hours, while twice this amount of either boiled pike or carp is similarly disposed of in 2 to 3 hours. Katsch (1926), in 75 observations on normal human stomachs, found that fish evokes a greater gastric secretion than beef and thus is more readily digested. Boiled fish is more easily utilized than red meat, according to Slowtzoff (1910). When smoked, it is somewhat less rapidly digested and is more nearly equal to beef. Geiger (1951) and Geiger *et al.* (1958), using purified diets, studied the rates of digestion of proteins in the rat. They concluded that casein disappeared from the gastrointestinal tract more rapidly than zein, but less rapidly than meat and fish proteins.

As early as 1911, White and Crozier reported on the readiness with which trypsin digested cod. This was somewhat slower with dogfish, with beef in between the two fish species. Holmes (1918) found that butterfish, Boston mackerel, grayfish, and salmon were readily digested by man. Schormüller (1937) established that pepsin breaks down egg albumin more readily than fish protein. The effect of trypsin was the reverse. On the whole, trypsin seems to be more active and better suited for fish flesh than pepsin (Baertich, 1950). Nilson (1955) performed experiments with six college-age women and demonstrated that fish had a digestibility of 89 to 96%, as compared to 87 to 90% for beef and chicken.

Determination of the "true" digestibility of fish in rats by correcting for the metabolic nitrogen in the feces has yielded such high values as 99% for salmon. El Rawi and Geiger (1952) similarly found that the proteins of tuna, sardine, and mackerel were well digested and absorbed. Jacquot and Creac'h (1950) reviewed this field (see Table X) and concluded that the utilization coefficient for fish protein ranged from 87 to 98%, varying with species. Sure and Easterling (1952), studying fish flour, obtained values of 70.7 to 97.8%. Bender (1958) found an exceptionally good digestibility coefficient with defatted, deodorized fish flour of the Atlantic cod, herring, and sardine.

Fish meals in some cases show a reduced digestibility, due to processing conditions—see further Section XII.

Another aspect little studied has been the capability of maintaining a nitrogen equilibrium. This differs appreciably. In this respect, dogfish was valued higher than cod, although the latter species was hydrolyzed more rapidly by trypsin (White and Crozier, 1911). Other factors obviously enter into play in such evaluations.

Because the determination of the true digestibility of proteins in animal and human experiments is time-consuming and expensive, the use of *in vitro* methods has been proposed (Adachi *et al.*, 1958). Generally, the values obtained in *in vitro* experiments parallel the *in vivo* digestibility; however, the order in which the breakdown products are released may be entirely different. *In vitro* methods promise to be most useful in deciding whether technological procedures have altered the digestibility of fish products.

TABLE X

SELECTED DIGESTIBILITY DETERMINATIONS[a]

Food	Digestibility
Coalfish	0.87–0.89
Haddock	0.98
Herring, dried	0.93
Mackerel	0.93
Cod	0.97
Cod, dried	0.95
Poronotus sp.	0.92
Salmon	0.98
Salmon	0.96
Salmon, canned	0.93
Skate	0.93
Redfish	0.98
Beef	0.87–0.89
Beef	0.98
Milk, cow's	0.87
Milk, cow's	0.95
White bread	0.87
Whole wheat bread	0.68

[a] Source: Jacquot and Creac'h (1950).

The factors responsible for the relative ease with which fish is digested are poorly understood. Recent investigations by Hamoir (1953, 1955) on the nature and structure of fish muscle protein may shed some light on this problem. It was found that "fish muscles differ from mammalian muscle in their very low content of connective tissue and perhaps in their content of albumins." A further characteristic seems to be "a much more loose association of its different structural elements as revealed by the easy release of tropomyosin and actomyosin." The shortness of the fibers of fish muscle may also play a part.

Saha (1940b) studied the effect of boiling and frying on the enzymic hydrolysis of fish proteins. By subjecting fish flesh to pepsin and trypsin, separately or combined, the degree of digestibility was established by measuring the amount of soluble nitrogen and α-amino nitrogen released through such enzymic action (Valanju and Sohonie, 1957c). All fish proteins, with the exception of that of "ghol," released a greater percentage of α-amino nitrogen that casein. Black pomfret is the most readily digested of all the investigated fish. Autoclaving the fish for one hour at 15-lb. pressure did not change the digestion rate of the enzymes investigated (Valanju and Sohonie, 1957c). Several observations were made as to the order in which individual amino acids were released. Isoleucine and lysine become available early in the digestion—in contrast to casein, where these same acids appear only at a late stage. As the Indian diet is particularly short in those two amino acids, this might have special significance.

Applying a treatment with pepsin for 3 hours, followed by the use of pancreatin (3–24 hr.), it was established that the digestion rate of fish flesh was reduced when the fish was either marinated, broiled, or deep-fat fried. Salted products showed the slowest rate of digestion, while boiled, steamed, or dried fish did not substantially differ in this respect from raw fish (Ito, 1959). Koval'chuk (1954a) found that the digestibility of defrosted cod measured through pepsin digestion is considerably reduced subsequent to a protein-coagulating heat treatment (see further Section IX, F). The digestibility is directly related to the solubility of the proteins.

Ambe and Sohonie (1957b) discovered a difference between trypsin and pepsin in their readiness to digest fish flesh (skate and shark), as compared to when they were acting on casein. The fish proteins are almost completely hydrolyzed to soluble components by the action of pepsin. This hydrolysis is slightly less in the casein, which is very quickly and more completely digested by trypsin. There is also a considerable difference between fish protein and casein as to the sequence in which amino acids are liberated when hydrolyzed by trypsin.

These findings contrast somewhat with later reports (Masheklar and Sohonie, 1959a) that all the amino acids except tyrosine were released more readily from casein than from the fish proteins. Against the background of this conflicting evidence, it appears somewhat premature to conclude, as these authors do, that casein has a greater value than these fish proteins.

Morrison and McLaughlan (1961) observed that the lysine in those fish flours that gave the lowest PER was less available by rat bioassays than that in the other samples. The variation in nutritional value could not be ascribed to differences in the total lysine, methionine, and cystine contents of the samples, but reduced amounts of lysine and methionine were released by pancreatic digestion of the flour which gave the lowest PER value. It was suggested that this effect might be explained by a reduction in the rates of release *in vivo*.

Changes in Storage and Processing

A. General

Comparatively little fish is eaten immediately after being caught. Most is stored and preserved for transportation or further use by freezing, salting, drying, smoking, or canning. In underdeveloped countries the preparation of fish pastes and sauces by autolysis is common (van Veen, 1953; Cutting and Bakkert, 1957) (see further Chapter 12, Volume III).

Recently, methods for the production of fish flours from comminuted fish by combined drying and extraction has become popular. Fish meals and soluble products manufactured by a number of different methods are widely used in the poultry industry in particular and in animal nutrition in general. As fresh fish is baked, steamed, fried, or boiled before being consumed by human beings, it becomes a matter of paramount importance, therefore, to determine the influence of these various processes on the amino acid composition, digestibility, and, secondarily, on the nutritive value of fish. This entire field is reviewed by Tarr in Chapter 6 of this volume and in an earlier paper by Bailey (1951). A few general comments will, therefore, suffice.

B. Spoilage

When fish are improperly preserved, microbial decomposition may affect the amino acid content of fish and in some cases lower the value of fish protein. It is often difficult, however, to decide whether the partial destruction of some amino acids or the presence of toxic bacterial metabolic products is responsible for this apparent decrease in the nutritional value. In rats, guinea pigs, dogs, etc., high histamine doses were found inactive when fed *per os* (Geiger, 1955).

Autolysis due to the digestive action of tissue enzymes may also occur under such conditions. This may alter the texture, flavor, and appearance of the fish product but seldom affects its nutritive value. Such is not the case, however, when fish protein is subjected to extreme autolysis, as in the production of fish pastes. Apparently complex chemical changes take place during this process. van Veen (1953), in his authoritative discussion of this subject, concluded that "the chemical composition of the intermediate and end products in fish pastes and sauces is for the most part terra incognita." This is also true, unfortunately, of their nutritive value.

Shifrine *et al.* (1959) recently reported, however, that diets containing high levels of histamine, as a result of bacterial decarboxylation, depressed the rate of growth and the total growth of chicks.

C. LOW TEMPERATURE

The effect of freezing and subsequent storage on the biophysical and chemical properties of fish muscle has recently been studied by British and Canadian investigators, but few data are available on the effects of these processes on digestibility and nutritive value. No significant change in amino acid composition was established on nine fresh-water fish in United States studies (Ingalls *et al.,* 1950). Some loss of protein is inevitable through drip (Seagran, 1958). All procedures conducive to a reduction in the amount of drip thus save proteins and amino acids, since the protein in the drip is primarily of intracellular origin (Seagran, 1958). Only a very minor change in the net protein utilization values for hake and croaker when frozen, was reported by Pujol and Varela (1958).

D. DEHYDRATION

The effect of drying seems to depend on how carefully the dehydration has been performed (Rice and Beuk, 1952). The senior author many years ago received, through the courtesy of Professor Wilder, samples of commercially available sun- and air-dried cod from Newfoundland. The growth-promoting properties of these samples in rats was identical to that of locally obtained fresh cod on the basis of nitrogen content. Long storage or excessive heating, however, particularly when the product is exposed to the air, may decrease the physiological availability of the amino acids of fish protein. This is primarily the result of the formation of enzyme-resistant linkages rather than amino acid destruction, since treatment with strong acids or alkali liberates the amino acids in their original amounts. The presence of such linkages is usually the explanation for the disparity observed between the biological values, derived from animal experimentation, and those calculated from the amino acid content of the protein. No impairment of protein digestibility due to dehydration was detectable in haddock (Adachi *et al.,* 1958). Pepsin was employed in these digestion tests and the PDR-index computed.

Sun-drying, according to Indian findings on two important food fishes ("ruhee" and "kibi"), appears to result in higher biological values than steam-drying (Basu and De, 1938).

Lysine and occasionally arginine are frequently inactivated by the formation of heat-induced bonds. According to Carpenter (1958), this is due to the reaction between the amino group of these amino acids and other active groups within the protein. Carpenter *et al.* (1957) has developed a colorimetric method for the determination of the nutritionally available lysine present in a protein, and a biological method has been devised by Grau *et al.* (1959).

When fish proteins are heated in the presence of carbohydrates, certain amino acids are destroyed owing to a Maillard type of reaction. Absolutely fresh meat contains, in nature, insignificant amounts of carbohydrates. But as spoilage starts, ribose is released. The mechanism for the post-mortem formation of this sugar is not entirely clear. The relative role of RNA (ribonucleic acid) and ATP (adenosine triphosphate) remains to establish. It is evident that muscle ribosidase is involved (Tarr, 1954, 1958; Shewan and Jones, 1957). At any rate free ribose accounts for much of the Maillard type of browning reactions (Tarr, 1953, 1958). Tappel (1955) has assumed that when fish is stored at temperatures above freezing, the oxidation of the highly unsaturated fats present in fish oil may form compounds which could induce a similar reaction. In order to investigate this possibility, Lea *et al.* (1960) studied the changes occurring in herring meal that had been stored at 25°C. for 12 months. The nutritive value and the available lysine decreased slightly, but no formation of "co-polymers," as assumed by Tappel (1955), could be demonstrated.

Stansby and Brown (1958) reported that a carbonyl-amine reaction and coupling have a "relatively minor" part in the browning or "rusting" that occur in fish meat.

Several investigations, including those conducted in the laboratories of the senior author, suggest that in some cases the oxidation of the films of polymerized fatty acids which tend to coat protein articles may delay or prevent the action of proteolytic enzymes. Thus, extraction of the fat with polaric solvents often improves the digestibility and nutritive value of fish meals. Other factors, however, might account for these findings. Almquist (1956) discovered that the amount of pepsin-indigestible protein does not increase with storage if the samples are vacuum-sealed, which indicates that oxidation produces progressive changes in the protein itself.

Extensive new investigations on Atlantic cod by Jones (1959b) have revealed the intricate biochemical relationships of browning. His findings supported the previous theory that the browning discoloration is coupled with off-flavors and intimately associated with changes in the muscle extractives, particularly the free amino constituents and the free sugars. During icing prior to drying, the compounds which are potentially browning-reactive change considerably. The free sugars in the flesh limit the extent of browning, glucose being important in the early stages and ribose later. The net effect is little change in the susceptibility to browning.

Anserine and L-methylhistidine sugar reactions are key substances according to Jones (1955, 1959b). Minor browning comes from a spontaneous degradation of L-methylhistidine, even in the absence of sugar. Taurine and β-alanine together show higher browning reactivity than β-alanine alone owing to an increased chain-length between the amino and acid groupings. The higher reactivity of taurine compared with β-alanine demonstrates the effect of substituting sulfonyl (for carboxyl) in an otherwise identical molecule. Valine and leucine gave little brown coloration under the same conditions. It is suggested by Jones that the low reactivities of valine and leucine and, perhaps, creatine result in steric effects similar to those anticipated by Schwartz and Lea (1952) in protein-sugar interactions.

A high rate of browning is frequently accompanied by a rapid loss of ribose. Loss of amino compounds gave a poorer correlation with browning than the disappearance of sugar (Jones, 1959b). The major contributors to both browning and the loss of sugar from the extractives of fresh muscle are anserine and taurine. As the muscle spoils, the effects of these two compounds diminish. Then α-alanine, L-methylhistidine, and lysine become increasingly important. Two of the major "extractives" in the muscle—creatine and trimethylamine oxide—contribute little to the browning reaction.

After a prolonged browning of muscle extractives, the loss of amino acids may eventually greatly surpass the sugar loss. Whichever the causal relationships of browning may be, it is evident that such a discoloration might change the nutritive effect of the proteins or that of the exogenic acids. Particularly important would be the reduction of lysine, (Reinius, 1956) due to its key role in the supplementation effect of fish and fish products.

E. CANNING

The senior author has investigated the effect of canning on tuna, sardine, and mackerel and has found, in agreement with Jarvis (1943), Dunn *et al.* (1949), and Neilands *et al.* (1949), that carefully controlled processing does not alter the amino acid composition or nutritive value of fish. Identical results were reported by Proctor and Lahiry (1956) with heat-processed shad and cod. On storage, lysine appears to be affected most in the inevitable loss of protein solubility in 5% NaCl (denaturation). In addition, the following acids were found to be adversely affected: arginine, methionine, cystine, tyrosine, and tryptophan (Sawant and Magar, 1958). So far, these observations are limited to East Indian packs.

Canned sardines stored for four years showed only a very slight decline in the PER ratio, from 2.7 to 2.9 (Lanteaume *et al.*, 1959). A slight loss of lysine may take place, thus reducing the over-all value of the fish protein (Bailey, 1951). The sodium chloride solubility was reduced 50% in a 12-month period (Sawant and Magar, 1958).

Browning may occasionally develop in the heat-processing of fish products. Free reducing sugars and the degree of browning grew in parallel with the length of storage of the fresh fish. Through free autoclaving, reducing sugars were decreased. Browning did not occur in flounder flesh below 120°C., but the flesh was browned at 100°C. by the addition of glucose, and at 80°C. by the addition of ribose (Ono and Nagayama, 1959).

F. COOKING

Several authors have studied the effects of cooking techniques. Marks and Nilson (1946) demonstrated that baking, broiling, boiling, and simmering did not change the nutritive properties of cod. Martinek and Goldbeck (1947) have shown that baking at 375° to 500°F. did not reduce the nutritional value of croaker fillets. Nilson *et al.* (1948) found that pan-fried, sautéed, and broiled striped bass have a supplementary value to rats, matching that of fresh fish. Finally, Nilson (1955) concluded that there is no essential difference between different cooking methods as to maintenance of nutritive value, nor is there a basic difference between the changes taking place in preserving fish as compared to its preparation through cooking. Cooking had no detrimental effect on the preparing of haddock for meals (Adachi *et al.*, 1958). On the contrary, a noteworthy increase in the nutritive value was observed in both fresh and dehydrated haddock. This change has not been explained.

Saha and Guha (1940) report the interesting observation that, in measuring digestibility on the basis of enzymic digestion, underdone fish flesh is most readily converted. Raw, fully-cooked, and fried fish meat are all less digestible. This result merits further exploration. Fish prepared in heated, but not boiling, water generally has a superior taste and texture. Koval'chuk (1954a) established that muscle protein of fish starts coagulating at approximately 30°C. and stops at 60°C. After this temperature no damage is apparent until 125°C. was reached. At 130°C., signs of degradation appear. The digestibility is influenced by heat treatment (see Section VIII and also Ito, 1957).

During heat-processing of herring at 115°C., Hughes (1960) found that about one-quarter of the creatine in the flesh of the herring is converted into creatinine. Furthermore, an over-all loss of total creatine plus creatinine occurs. This is due to a physical binding on the flesh proteins during thermal coagulation. It is suggested that occlusion by or adsorption onto the proteins takes place, thus rendering the creatine unavailable for extraction.

Some change in the amino acid content through the frying of fish was found in several fresh-water species (Ingalls *et al.*, 1950). The percentage of leucine, lysine, phenylalanine, and valine was a third less in the protein of the fried fish as compared to the fresh fish. There was some loss also in isoleucine. The change in the percentage of methionine and threonine in the fried fish was not significant.

G. MISCELLANEOUS

There is no consistent evidence that serious damage results from the defatting and deodorization whereby fish meals are converted into fish flours (Bender and Haizelden, 1957). Haddock fillets were sterilized adequately by cathode rays in the range of 0.9–5.7 million rep, without adverse effect on ten major amino acids in fish muscle. Losses below 10% were noted in such key acids as lysine, methionine, and tryptophan (Proctor and Bhatia, 1950).

X. The Supplementary Value of Fish Protein

The potential use of inexpensive products and fish wastes as a protein supplement is great. The total supply of amino acids provided by a meal determines its nutritive value rather than the algebraic sum of the nutritive values of the individual constituent proteins: thus, the nutritive value of a meal containing mainly vegetable proteins that are deficient in certain amino acids can be greatly improved by the addition of small amounts of fish protein (Gounelle, 1958; Mauron and Mattu, 1960; Mauron *et al.*, 1960) (see also Table XI).

TABLE XI
EAA COMPOSITION OF SELECTED PROTEINS

Amino acid	Maize (corn)[a]	Millet[b]	Groundnut (peanut)[a]	Fish[c]
Lysine	2	2.7	3	6.6
Arginine	4	3.6	9.9	5.5
Histidine	2.4	2	2.1	1.2
Tyrosine	6.1	—	4.4	2.9
Tryptophan	0.8	1.75	1	1.6
Phenylalanine	5	3.9	5.4	4.1
Cystine	1.1	1.25	1.6	—
Methionine	—	2.35	1.3	3
Leucine	21.5	16.75	5.5	10.5
Isoleucine	3.6	4.95	3.4	7.7
Valine	3.6	4.35	4	5.3

[a] Block and Bolling (1945, 1951).
[b] Adrian *et al.* (1956).
[c] Deas and Tarr (1949).

Mutual supplementation of proteins has been utilized in many parts of the world for ages. Many civilizations empirically developed the practice of adding fish pastes or dried fish to meals in which grains or other vegetables served as the staple. Intelligent application of the principles underlying such practices, however, had to wait until the amino acid composition of most proteins had been established. More recently, it has also been recognized that, in order to achieve an improvement of the nutritional value, the deficient and the supplementary proteins have to be fed simultaneously.

A. Dietary Findings

Observations from Senegal on the favorable effect of fish and shellfish as a food supplement have been mentioned in the introduction (Autret and van Veen, 1955). These findings were confirmed by Doutre (1959). In later Senegal studies, a combined antimalaria campaign and a protein supplementation, using fish flour as an added ingredient, gave equally impressive effects. The infant mortality rate fell by nearly two-thirds (Raoult, 1956). A noteworthy salutary effect in the use of fish becomes evident in Nigeria, when the fishing population is compared with adjacent farming groups. The first groups were better provided with animal protein and in better health. This has been further discussed and analyzed by Borgstrom in Chapter 7 of this volume.

Such fermented fish products as nuoc-mam, mam-tom, prohoc, and padu are indispensable supplements to the diets of rice-eating people, according to the investigations by Brémond and Rosé (1919).

B. Experimental Findings

The supplementary value of fish protein is independent of its nutritional value and varies with the amino acid deficiencies of the diets which are to be supplemented (Table IX). In experiments conducted by the senior author, it was found that certain fish meals having a low biological value when fed to chickens as the sole source of protein proved to have an excellent supplementary effect when fed at a 3% level in a diet containing plant proteins. In this case, the amino acids destroyed or made physiologically less available by the processing of the fish meal were not those required for the supplementation of the deficient protein. Similarly, fish meals produced from head, tails, and bones, which contain chiefly collagen protein that is low in tryptophan, are inadequate when fed alone but make efficient supplements for vegetable proteins. In general, cereal proteins are short in lysine, methionine, and, to a lesser extent, cystine, isoleucine, and threonine. Fish protein contains ample supplies of these amino acids and is, therefore, effective in supplementing diets composed mainly of plant products, primarily cereal grains (Costamaillere and Ballester, 1956; Sure, 1957a, b, c; Cravioto *et al.*, 1955; Carpenter *et al.*, 1957; Morrison and Campbell, 1960). On the other hand, fish protein contains relatively little tryptophan and is ineffective when diets are low in this amino acid. Dried fish is, according to the balance method, an excellent means of supplementing the protein of pulses, such as peas, lentils, and green gram (Basu and De, 1938). These findings contrast with those reported by Schiller (1957) showing that fish meal adequately supplements barley and potato, but not pulses.

1. *Laboratory Animals*

Sure (1957a, c) reported that an increase in the body weight and a higher protein efficiency ratio can be obtained in the albino rat by the addition of small amounts of defatted fish flour to millet and sorghum. Kik (1956) studied the growth and metabolism of young rats fed on diets supplemented with perch meal (see Table XII). He found that when 1.3 or 5% perch replaced an equivalent amount of protein in milled rice, an increase in body weight of 111.1, 111.1, and 100%, respectively, was observed.

TABLE XII
AMINO ACID COMPOSITION OF WHOLE RICE AND PERCH[a]

Amino acid	Rice (% of protein)	Perch (% of protein)
Arginine	9.0	7.3
Aspartic acid	4.9	6.4
Cystine	1.7	1.4
Glutamic acid	11.7	14.6
Glycine	6.4	6.5
Histidine	3.1	2.1
Isoleucine	4.8	5.1
Leucine	8.0	7.1
Lysine	3.7	8.1
Methionine	3.3	4.8
Phenylalanine	4.4	4.6
Proline	5.3	3.0
Serine	4.6	6.4
Threonine	3.9	4.8
Tryptophan	1.3	1.3
Tyrosine	4.1	3.8
Valine	7.1	6.2

[a] Source: Kik (1956).

Fish flour is a first-rate supplement to most cereal proteins (Table X). Its effect was studied on wheat and maize (corn) and compared to simple addition of lysine. In the last case, fish flour was superior, offering, in addition to lysine, the limiting acid tryptophan (Rerat and Jacquot, 1956). Fish meal was superior to groundnut (peanut) meal as a supplement to poultry feed at 3.75% level (Carpenter and Clegg, 1957). Fish meal also turned out superior to soybean meal as a supplement to barley or potato in the feeding of hogs and poultry (Schiller, 1957). The effect was equally pronounced whether employing cod or herring meal. Ballester *et al.* (1958) reported not so favorable results in supplementing a "poor" Chilean diet. Rats were used in these experiments. Good effects of adding 3% fish flour to East Indian diets were reported by Metta (1960), also on the basis of rat studies.

2. *Human Beings*

Albanese *et al.* (1955) have reported that the nitrogen retention of underweight infants could be enhanced by lysine supplementation to bring their milk diets to the lysine:tryptophan ratio (L:T) of meat. According to these authors, an L:T ratio in the range of 5 to 7 is associated with the highest efficiency of protein utilization. The protein from the Philippine fish dilis (*Stolephorus commersonii*) has an L:T ratio of 7:4.

Kik (1956) studied the value of ocean perch protein for supplementation of a human diet of milled rice. Such protein compared most favorably with the effect of added synthetic amino acids, such as lysine and threonine, and had an equivalent effect which is readily explained by its aminogram (see Table XII). Adrian *et al.* (1956) found fish autolyzate, enzymically prepared, most efficient as a supplement to a one-sided millet diet as practiced in tropical Africa. The amino acid analyses explain this clearly. Peanut meal is almost as efficient, but larger quantities are required—90 g. of peanut flour per day against 18 g. of dried fish autolyzate. Lysine is twice as potent in the fish product as compared to peanut protein (see Table XI).

As rice also is deficient in lysine and threonine, fish flour is particularly suitable as an improver of diets where this staple predominates. In powdered form, it has less bulk and can be made available to areas far from sources of fresh fish or fresh animal protein. It easily blends with milk, soups, cakes, cookies, or other food preparations—see further Section XI.

Millet and corn are widely used in tropical Africa. Even in this case, fish constitutes an ideal supplement (Sure, 1957b, c). This is best elucidated by Table XI extracted from a French study (Adrian *et al.*, 1956). They concluded that on the basis of a daily consumption of 600 g. of millet, a supplement of 90 g. of groundnut flour together with 10 g. of fish flour gives complete coverage as to EAA. Corresponding figures are valid for corn (maize), but fish flour is not adequate when added to manioc flour, which is still poorer in its protein aminogram. Several effective diets were employed in the treatment of kwashiorkor in Dakar (West Africa). Among these diets was one consisting of millet and peanut presscake with 7% fish—see further Table XIII. Potassium must also be added in order to obtain curative effects (Sénécal *et al.*, 1956). Protein hydrolyzates are more effective than whole protein, indicating possibly that free amino acids are more readily available to the protein-deficient child body (Sénécal, 1958).

TABLE XIII
COMPARISON OF AMINO ACID CONTENT[a]
(Calculated per 100 g. protein)

Amino acid	Peanut	Millet	Fish	Cow's milk	Egg
Arginine	9.95	4.70	8.27	3.5	6.4
Cystine	1.6	1.25	—	0.7	2.4
Histidine	2.1	2.10	2.63	2.4	2.1
Isoleucine	3.0	4.30	6.00	6.6	8.0
Leucine	7.0	17.40	9.72	11.8	9.2
Lysine	3.0	2.60	9.72	8.1	7.2
Methionine	1.15	2.60	2.63	2.2	4.1
Phenylalanine	5.2	4.90	4.45	4.6	6.3
Threonine	1.95	4.90	5.18	4.8	4.9
Tryptophan	0.95	2.30	0.81	1.4	1.5
Tyrosine	4.4	2.00	2.54	6.2	4.5
Valine	8.0	5.65	6.54	—	7.3

[a] Source: Sénécal (1958).

The combination of fish with millet or with peanuts is of great benefit. This produces well-balanced protein sources. Thus, the lysine content of fish flour is high, in fact exceeds that in eggs. On the other hand, the tryptophan level is low, but fortunately this is compensated for by the millet. The level of methionine content, although superior to that in milk, is considerably less than that in eggs, but still adequate.

Corn and cassava are dominant ingredients of the Latin American diet in many regions. Fish flour has proved to be an excellent supplement to a tortilla diet (Cravioto *et al.*, 1955).

Sesame seed and sesame meal are important both as human food in many areas of the world and as a poultry feed. Dried buffalo-fish, when replacing 1%—out of 9% sesame meal protein—induced a 36.7% gain in body weight and a 21% increase in protein efficiency ratio (Kik, 1960).

Much of the experience in this field comes from the common and extensively investigated practice of supplementing poultry feeds with fish meal (Lanham and Nilson, 1947; Grau, 1952; Almquist, 1957; Rand *et al.*, 1958). Many articles have been published in the poultry literature which indicate that the growth of the animals, quantity and quality of eggs, and meat production improve and become more economical when the starter, broiler, or layer rations are enriched with fish protein—see further Chapter 9, this volume. Furthermore, the value of the fish meal so employed has been found to vary with quality of the original material, type of processing, and length and conditions of storage.

XI. Fish Flour

Fish meal specially prepared to be used as human food has been given the designation of fish flour. It is, however, to be looked upon primarily as a protein concentrate and not, mistakenly, as any substitute for grain flour.

Recently, a well-planned world-wide research project was initiated by the FAO of the United Nations with the cooperation of the WHO to develop protein supplements which could improve the amino-acid-deficient diets consumed by children and adults in many parts of the world. One of the promising results of this effort has been the development of deodorized fish flours that are high in protein and low in fat. These flours are produced by the extraction and low-temperature azeotropic dehydration of the degutted fresh fish meat with organic solvents (Dreosti and van der Merme, 1955–56; Levin, 1956, 1959). The finely ground flour is then washed repeatedly with alcohol to remove traces of solvent and deodorize the product. Careful processing and storage are required in order to maintain the full nutritive value, easy digestibility and palatibility, and to prevent the introduction of bacteria, foreign material, or such toxic substances as histamine, peroxides, or polymerized oils. Several other methods have been investigated and also tried commercially (see Chapter 19 by Borgstrom). Recently, Canadian investigators reported on an improved extracting method producing flour of superior quality (Guttman and Vandenheuvel, 1957).

The safety of some of the fish flours produced for the FAO has been investigated recently in the laboratory of Allison *et al.* (1958). The results of these studies can be summarized as follows: the substitution of fish flours in various concentrations for casein in the diet of rats did not significantly alter the food efficiency, and during the 6 months' feeding experiments no changes in blood cytology, platelet count, prothrombin, or coagulation time occurred. All organs investigated histologically showed findings within normal limits. In dog experiments the fish flour was well digested and had a high nutritive value which was similar to milk protein in its ability to maintain nitrogen equilibrium in adult dogs.

Allison also found that 12 months' storage or deodorization did not alter the nutritive value of fish flour. Small amounts (1, 3, and 5%) of defatted fish flour made from defatted carp, smelt, whiting or mixture were added to diets of rats containing protein from milled wheat flour; white corn (yellow corn, sorghum, and millet) meal; and polished rice. These supplements had a far superior effect on body weight increase and protein efficiency than did dried nonfat milk meal, defatted soybean flour, yeast or peanut meal (Sure, 1957a, b). This is evident from Table XIV.

TABLE XIV[a]
EFFECT OF FISH FLOUR AS A SUPPLEMENT

	Fish flour (%)	Biological value (%)	PER (Protein efficiency ratio)
Millet	1	31.3	8.6
	3	117.0	26.0
	5	343.2	98.1
Sorghum	1	193.7	128.3
	3	409.5	186.8
	5	644.4	213.2

[a] Source: Sure (1957a, b).

Somer *et al.* (1958) in El Salvador has investigated the supplementary values of a number of fish flours. These flours, containing 83% protein, were fed to children for 18 weeks in daily quantities of 20 to 30 g. without showing bad effects. The children receiving tortillas made with 3% fish flour gained more weight than control groups. Patties containing equal amounts of fish and wheat flour were also well accepted, and fish flour was also given successfully mixed with milk, soup, and bean dishes. Somer also found that the addition of fish flour to the diet will definitely prevent marasmus and kwashiorkor.

Preliminary results published by Gómez *et al.* (1958) indicate that fish flour had no ill effects on children when mixed with soups, beans, hard biscuits, cereals, tortillas, and bread. No anorexia was produced. It was concluded that fish protein "constituted a real nutritional contribution for the recovery of undernourished children." It should be emphasized, however, that no way was found by these authors to introduce fish flour into infant formula. Autret and van Veen (1955) suggested the use of fish flour as a possible source of proteins in child feeding. They believe the edible fish flour offers a cheap and yet convenient source of proteins for the child because of its high content of good quality protein. In addition, fish flour is a good source of calcium and vitamin B_{12} when containing whole fish or part of viscera.

Sénécal *et al.* (1956) and Sénécal (1958), from French West Africa, and Dean (1952), from Uganda, also report that fish flours satisfactorily supplemented diets based on millet, where lysine is the chief, and cystine together with isoleucine the secondary, limiting factors. Good supplementation was also obtained when fish flours were added to peanut diets in which the chief deficiency apparently was methionine, but isoleucine and lysine were also present in suboptimal amounts. Brock and Autret (1952) consider the use of dried fish, fish pastes, or fish flour as supplements to be the most efficient and economical way to prevent kwashiorkor. Ramamurty (1955) from India and Villadolid and Pidlaoan (1954) from the Philippines all reported favorable results of adding fish flour to various common foods. Three clupeids gave a flour which, besides containing much calcium and phosphorus, had a good protein content with favorable dietary effects (Doutre, 1959).

Beneficial effects of adding fish flour to one-sided, deficient diets have been reported by a number of researchers and field workers (Gounelle, 1958). On the whole, properly processed fish flours constitute an excellent dietary supplement in all areas of the world where protein malnutrition is prevalent (Table XV). Several favorable results are reviewed in a 1958 FAO report (Anonymous, 1958a). One drawback is undoubtedly the variation in composition for most fish flours due to species, season, and processing method. Standard values for amino acid content have restricted applicability (Autret and van Veen, 1955). Digestibility may also vary with the above-mentioned factors.

Fish flours are not without their detractors. Some clinicians and nutritionists in this field have found that fish flour is encountering more than the usual amount of resistance accorded the introduction of any *new* food, and in instances children and adults have repeatedly refused to eat fish flour, even in a disguised form. It is to be anticipated that technological advances will enable more palatable products of better texture to be produced, for fish flours offer the nutritionist a real hope in combating the many serious illnesses that result either directly or indirectly from amino acid deficiencies. In many parts of the world—particularly those accustomed to various fermented products—pronounced flavor offers no detraction. Adults in Indonesia even prefer such a product to flavorless flour (Autret and van Veen, 1955). It cannot, however, be denied that practical experience proves the great difficulty of manufacturing a uniform high-quality product with reasonably stable characteristics from one batch to another. Too often a sample of high quality flour has been followed by a delivery of a low-grade merchandise. This undoubtedly reflects the infancy of the industry rather than deceptive procedures. Difficulties still prevail in the industry in regard to the tech-

TABLE XV
MILLIGRAM AMINO ACIDS PER GRAM OF TOTAL NITROGEN IN FISH FLOUR[a]

	Tryptophan	Threonine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Valine	Arginine	Histidine
Average	62	360	348	509	607	166	234	322	428	106
Maximum	76	449	468	846	1058	197	292	396	500	150
Minimum	54	188	280	392	493	143	84	267	345	76

[a] Source: Orr and Watt (1958).

nical methods followed and the availability of a uniform raw material; entirely reliable methods are lacking for the right handling both of the raw material and the final product. Incipient spoilage of the raw product undoubtedly explains the cases of poor quality.

Tests with premature babies prove that the good quality of codfish protein fully supported normal growth and in this respect was equivalent or even superior to milk (Schäfer and Grüttner, 1957).

A crude, but efficient, fish flour has been manufactured on a pilot-plant scale by the Philippine Institute of Fisheries Technology to serve as a supplement in improving the quality of protein of the average Filipino diet. Dilis—the long-jawed anchovy—was used as raw material. The fresh fish are washed in water and then dried thoroughly under the sun or in the air. Subsequently, the dried product is passed through a ball mill, making it finely powdered. A second type is the deodorized fish flour, prepared by extracting the raw fish flour three or four times with alcohol and then drying the extract at low temperature under vacuum. The resulting product is nearly odor-, taste-, and saltless; it enjoys a higher consumer acceptance than the raw flour (Alcaraz-Bayan and Leverton, 1957a). The amino acid composition of deodorized flour is similar to those of raw flour, indicating that deodorization did not significantly affect the amino acid content of the raw dilis flour (Alcaraz-Bayan and Leverton, 1957b). There is a close similarity in the tryptophan content of such dilis flour with casein, whole egg, beef muscle, perch and other fish meals. Deodorized fish flour has a higher lysine and threonine content than casein and whole egg. The EAA values of dilis flour do not differ greatly from the values reported for casein, whole egg, and beef muscle. With regard to the non-EAA content, this dilis flour has a higher aspartic acid, arginine, and glycine content than casein, but contains less proline, serine, and glutamic acid. When compared with the other fish meals, deodorized dilis flour compares closely with the figures given by Kik (1956) for perch, Lahiry and Proctor (1956) for shad muscle, Neilands *et al.* (1949) for fish flakes, Block and Bolling (1951) for fish muscle, and Master and Magar (1954) for eight varieties of Bombay fishes.

A similar crude fish flour was manufactured out of whole fresh-water fish; this was well received in the Belgian Congo (Roels, 1957). Low-grade fresh-water fish was also the raw material source for the manufacture of so-called "mass" fish. The fish pulp was treated with 1% sodium hydroxide, and neutralized by 3.6% hydrochloric acid. The product was subsequently purified and dried through evaporation. The yield was 62%. This protein is used as a filler in canned meat products and sausages (Lorincz, 1951).

Fish perodically occur in large numbers in the coastal waters of Malaya, but several of these species are not easily marketable. The Department of Fisheries has developed a simple method of preparing the fish meal for human consumption which requires no elaborate or expensive machinery and which can be easily done even in the small fishing villages (Simpson, 1957). The species of fish chosen for these trials is "ikan tamban" (*Sardinella clupea*). The manufactured fish meal is free from pathogenic organisms and contains 73.2% crude protein, 3.7% lipids, 16.5% ash, and 4.2% calcium (Simpson, 1957).

According to Autret (1956), edible fish meal (fish flour) to be used in supplementary feeding should contain not less than 65 to 70% protein of a high digestibility coefficient and high biological value. Taking into account that the calcium and phosphorus ratio exceeds 1, and that edible fish meal can be a useful source of B_{12} and of other vitamins of the B group, it is a most effective supplement, even in small quantities, to cereal proteins. The fat content should be low. In protein supplementation, the most important factor is the nature and amount of EAA. Fish flour which gives protein utilization figures of 40% or above can be recommended.

Another way which has been investigated is the manufacture of biscuits fortified with fish flour (Mauron and Mottu, 1960). Additional ingredients are peanut flour, dried yeast, nonfat milk solids and corn flour. The heating in the making of these biscuits reduces the value of certain critical amino acids, namely lysine, methionine, and tryptophan. The molding of the biscuits to the rough processing without heating safeguards the original dispensability of these acids. The heating is chiefly responsible for this decline in nutritive value. Methionine becomes the primarily limiting amino acid.

Closely related to fish flours are dehydrated and purified fish proteins. In Germany these became an important substitute for poultry eggs during World War II. Several years of research by Metzner and Hittner preceded the introduction of this product to the German fish market under the trading name of "Wiking"—protein. As to these patents, see Winter (1949). This product became extensively used in cooking and in the baking trade.

Dehydrated protein has been studied by Baertich and Weber (1947) as to marine species and by Winter (1949) with leading fresh-water fishes. In both cases, a highly nutritive supplement was obtained through repeated extraction and purification. This is recommended as an efficient way to utilize large quantities of low-grade fish as human food. A similar method was developed by the Hungarian scientist Lorincz

(1951). This protein was used as a filler for canned meat products and sausages, and it improved the quality of those products.

Fish meal can also be made into an edible past. It is first softened and swollen by boiling 10–20 min. with 10 parts of 1% NH_4OH solution. Starch is then added and *Aspergillus oryzae* cultivated on the mixture. The molding fish meal is then mixed with NaCl and water, and the mixture is fermented 10–20 days at 30–35°. During such preparation, the monoamino- and cystine-N as well as lipids decrease, the properties of the lipids are changed and ergosterol formed (Higashi *et al.*, 1951–52). Drying fish by absorbing the water in starchy substances is the basis of the Protein Flour Process by de Vries. This product had a good consumer acceptance in trials in Belgian Congo (Lassance *et al.*, 1958).

Ways of using fish flour in various kinds of foods as well as a review of fish protein in new and old products and dishes are discussed in Chapter 7. Major Japanese dishes are presented in Chapter 8.

In a few cases hydrolyzates generally obtained through enzymic digestion have been studied as to their usefulness as food. Their content of total and digestible protein has also been analyzed (Pallardel Peralta, 1951). The histidine and methionine levels in hydrolyzates of several Peruvian marine fishes were likewise established (Pallardel Peralta, 1951). An improved fish meal was obtained by fermenting minced flesh together with defatted buttermilk, after which the material is dried and powdered (Pillai, 1956). Low-grade meal fish may after solubilization be dried into a good complement to human food (Yuditskaya, 1960).

The fermented fish products of South East Asia constitute another essential supplement to their one-sided rice diet because of their abundance in critical amino acids. For further discussion of this matter see Volume III, Chapter 20 by van Veen. Several studies of these products were made by French scientists (Brémond and Rosé, 1919), establishing their nutritive importance. Recently, investigations have been reported on Indian efforts to copy these fish sauces, in effect, protein hydrolyzates. Employing chiefly *Sardinella dayi*, a product similar to the Thai sauce "nam-pla" was made (Velankar, 1957). A product resembling nuoc-mam has recently been manufactured in Dakar (Toury *et al.*, 1958).

XII. Fish Meal

Quite early, fish meal was used as a dependable source of high-class protein for livestock (Kellner, 1877; Honcamp *et al.*, 1911, 1933). Their feeding values are critically reviewed in Chapter 8 of this volume—see also Table XI. Reference is also made to earlier surveys by Creac'h

(1950b), Bender *et al.* (1953), and Grau *et al.* (1959). A few remarks and general observations, nevertheless, seem justified.

Commercial fish meals were recently examined by Miller (1956) for their net protein utilization by rats and found to be of poorer nutritive value than laboratory fish preparations, which had a net protein utilization of about 80%. Chiefly responsible for this difference are the drying and consequent occurrence of the Maillard reactions.

No damage was detectable in the dried product after storing for 3 months at room temperature. For rats, methionine, the limiting amino acid in damaged meals, might be added with advantage to these products (Miller, 1956). White fish meal seems to be superior to both herring and whale meal, possibly due to the interference with digestibility by rats, even in defatted meal (Harrison *et al.*, 1935; DuLoit and Smuts, 1941). Although all the following three species belong to the fatty fishes, meal of menhaden consistently appeared inferior to sardine and herring (Barrick *et al.*, 1943). No explanation is available for this.

A considerable number of results are published, describing growth tests on fish meals, but only a limited amount of nitrogen balance studies appear to have been carried out. These show values for net protein utilization ranging for oily fish from 41 to 85% and for white fish from 60 to 90%. During the 1930's, a number of comparisons were made of products taken from various types of driers. These showed that the nutritive value of vacuum-dried meals was better than those produced in steam driers, which in turn were superior to flame-dried meals (Maynard *et al.*, 1932). Some recent growth tests have demonstrated that differences are minor between the three standard methods of drying (Bissett and Tarr, 1954). Although this may be disputed by some authorities, the present favorable findings may still reflect the improved techniques in the industry.

Fish meals are produced either from whole trash fish or from the offal or "cannery scrap" that remains after the choice parts of the edible fish have been removed. The freshness of the material is not an especially important factor since satisfactory fish meals can be produced from slightly stale or autolyzed fish as long as extensive microbial decomposition has not destroyed the EAA (Grau and Williams, 1935; Lassen *et al.*, 1951).

Certain minor differences exist between species. Meals of redfish and mackerel have a slightly higher nutritive value than those of herring, and these in turn are all superior to tuna (Nehring, 1956). On the other hand, when fed to poultry, sardine meal appeared in all respects equivalent to Norwegian herring meal, according to Ladrat *et al.* (1958).

Spontaneous heating leads to a destruction of amino acids, being more pronounced for lysine, tryptophan, cystine, and histidine (20–30%; see also Table XVI) (Boge, 1960). For most other amino acids investigated, the values are approximately 10% lower than for fresh meal. These chemical findings are supported by feeding tests (Laksesvela, 1958). There is a simultaneous browning in spontaneous heating, but supplementation with lysine could not compensate for the ensuing reduction of the growth rate of chicken. Other factors, must, consequently, be involved (Laksesvela, 1958).

The production of fish meal in open-flame or steam driers may result in the destruction or a decreased availability of EAA, unless special precautions are taken (Rice and Beuk, 1953). No effect on availability of EAA in herring meals by normal heating was reported by Tarr *et al.* (1951) and Bissett and Tarr (1954). Excessive heating, whether through long duration or high temperature, seriously impairs the quality of the product. The drying temperature should, therefore, be below 212°F. (100°C.) (Bender *et al.*, 1953). Studies by Thurston *et al.* (1960) on herring and tuna meals showed an effect on pepsin digestibility at higher drying temperatures. The differences were minor below 230°F. but became pronounced at higher levels. The inlet may, according to Minsaas *et al.* (1953), be high in a flame-drier, provided the outlet temperature in the manufacturing process is low. These research workers maintain that the effect is of a decreased digestibility nature rather than a direct deterioration of EAA. Maynard and Tunison (1932) report the biological value of herring meal as 70% when manufactured through direct heating, but 78% when made in a vacuum evaporator. Seventy-eight and 85% are the corresponding figures for haddock meal. Sure and Easterling (1952) found 86.4% for meal from the Pacific sardine, 86.9% for menhaden, and 79.7% for Alaska herring.

Commercial methods of manufacturing dehydrated fish are not always satisfactory (Lovern, 1951). Air oxidation and "self-heating" during storage may also induce dangers. Much of the data that have appeared in the literature on the supplementary value of fish meals cannot be compared because the authors have failed to provide the necessary information concerning the origin, method of production, or age of the fish meal used in their experiments. Thus, such diverse values as 36 and 86% for the biological value of fish meal have been reported. Wet-processed dogfish meal, when correction has been made for its high urea content, promoted growth and feed utilization of chicks, equally efficient to other fish meals customarily employed (Rhian *et al.*, 1942).

The value of herring meals as protein supplements when stored for one year at —25°, 21°, and 37°C. was unaffected. This is partly in con-

TABLE XVI

AMINO ACID COMPOSITION OF HERRING AND HERRING PRODUCTS[a]

Amino acid	Whole herring	Press[b] cake	Whole meal	Spontaneously heated meal	Press water	Solubles
	Grams amino acid per 100 g. of crude protein (N × 6.25)					
Tyrosine	3.0	3.3	2.9	2.6	0.7	0.7
Cystine	1.4	1.6	1.3	0.95	0.4	0.1
Glycine	6.3	5.4	6.3	5.6	10.2	10.9
Alanine	7.6	7.7	7.5	7.0	7.3	7.9
Aspartic acid	9.4	9.9	9.1	8.8	5.0	4.9
Glutamic acid	11.4	12.0	11.8	10.6	7.7	7.5
Proline	4.2	4.3	4.6	4.1	4.6	4.8
Serine	4.1	4.5	4.2	4.1	2.9	—

[a] Source: Boge (1960).

[b] Almost identical values in press-cake meal.

trast with the reported findings by Tappel (1955) that protein is also involved in the oxidation process of fats.

Controlled heating of herring meals dried at a low temperature does not lower the nutritive value of herring meals. In many instances chicks grew better with the heated meals (March *et al.*, 1961). From the results of these various experiments it appears that certain deteriorative changes in herring meal occur at a faster rate or take a different course when the processing and storage temperatures are low. Possibly antioxidants are formed at higher temperatures. This is a most noteworthy observation which merits further attention.

A number of methods for determining the supplementary value of fish meals have been devised. Almquist *et al.* (1935) introduced a "protein quality index" based on four different solubility tests which gives a positive correlation with actual growth tests with chicks (Evans *et al.*, 1944) (see Chapter 9 by March, this volume). Carpenter (1958) has suggested the use of a "growth protein value" which represents the growth in grams over a 2-week period, in excess of basal growth divided by the number of grams of supplementary protein consumed. Other methods have been proposed by Grau *et al.* (1959). The net protein utilization was measured by Bender and Haizelden (1957).

Miller and Platt (1956) have reported great improvement in the reproductive performance when a basal "Gambia-type" diet containing whole meal flour, haricot-bean meal, and alfalfa meal was supplemented with fish meal at a 10% level and fed to rats. Heavy losses occurred after weaning. Accessory food factors, such as vitamin B_{12}, could also explain this reaction.

Wastes from the fish-processing industry are frequently made into meal, and render very good quality with a surprisingly high nutritive value (Canales, 1951). The concentrated stickwater fish solubles are less important as a protein source than as a mineral supplement. Its merits are discussed in Chapter 9, this volume, and in Chapter 22, Volume III (see also Creac'h, 1950b). Primarily, this waste product was successfully utilized in the United States, and in latter years in other parts of the world also. Equally favorable feeding effects are reported with solubles as with other fish products (von Kraack, 1956). Fish silage products, using different chemical preservatives, are also important to many countries (see further Chapter 9).

XIII. Fish Solubles

Proteins in condensed fish solubles are, however, less useful to the chick and pig than the proteins of fish meal. By use of herring products, the inferiority of the solubles has been clearly demonstrated. Chicks may gain only about half as much on solubles as they do on herring meal, the test products contributing 6.3% of protein in a 13.5% total protein diet of natural feeding stuffs (Laksesvela, 1958). From a chick test with 3% herring protein, 11% total protein level and a standard natural diet, Carpenter (1954) reports a gross protein value of 95 for herring meal and 65 for condensed herring solubles.

The United States National Research Council lists fish solubles as carrying only about 50% of lysine and of "methionine plus cystine," about 60% of tryptophan and arginine, of the corresponding figures for meal protein. Recent assays of herring products confirm this ratio between meal and solubles for lysine and arginine, but for tryptophan and "methionine plus cystine" the solubles have been found to be even more inferior. In order of sequence, tyrosine, isoleucine, histidine, leucine, and valine are also found to be very low. Particularly low values were obtained for tryptophan and tyrosine, which amounted in the solubles protein to only about 20% of the corresponding meal figures. Contrarily, glycine has been found to be nearly twice as high in the solubles as in the meal (Boge, 1960). It has been assumed that the solubles lower the biological value of the meal, when they are added back to the press cake when so-called whole meal is produced, this resulting from their lower levels of amino acids, in particular "methionine plus cystine."

Examination of herring press water and condensed herring solubles shows that destruction of certain amino acids may occur during evaporation in the manufacturing. Cystine is almost completely destroyed, losses of histidine and tryptophan amount to 43 and 36% respectively (Boge, 1960). (For a more detailed discussion of these complexities reference is made to Chapter 16, this volume.)

XIV. Whale Protein

Whale muscle protein largely resembles that of terrestrial mammals and consequently has a high nutritive value. Many efforts are presently being made to extend the consumption of whale meal as human food—see further Chapter 7 of this volume. A few pertinent data as to its composition are in order.

The value of whale meal has been widely studied on livestock animals, and it has been extensively employed for feeding purposes. One kg. of whale meat (dry matter 92.5%) generally contains approximately 634 g. of digestible crude protein. Favorable feeding results have been obtained in both hogs and poultry (Breirem, 1940; Hvidsten and Husby, 1955). Whale meals are equal to fish meal as supplements to cereals in rations for nonruminants (Carpenter *et al.*, 1955). Early findings on the good feeding values of whale meal were reviewed by Honcamp *et al.* (1911).

Samples showed a great deal of variation as to biological value, protein content, and digestibility (Carpenter *et al.*, 1955; Bunyan and Price, 1960). Lysine is the decisive factor in high rating (Bunyan and Price, 1960).

The average aminogram of whale meat meal, according to Pritchard and Smith (1960), is given in the tabulation below.

Amino acid	%	Amino acid	%
Arginine	4.3	Cystine	0.7
Histidine	2.0	Methionine	1.4
Lysine	6.3	Threonine	5.6
Tyrosine	2.0	Leucine	6.5
Tryptophan	0.9	Isoleucine	4.3
Phenylalanine	3.8	Valine	2.4

These values do not entirely agree with those reported by Japanese scientists (Okuda and Yamafuji, 1934). Valine was almost three times higher, arginine and lysine were 40% higher, histidine 30% more, phenylalanine 35% less, and leucine half of these figures. The discrepancies could be explained by the present improved methods of analysis.

Soviet studies claim whale meat to be a potent source of tryptophan, making it a particularly valuable adjunct for food-enrichment programs with this amino acid (Nikolaeva, 1954). British scientists (Pritchard and Smith, 1960), maintain that whale meat meal can be employed primarily to overcome the lysine and threonine deficiency of wheat protein.

Japanese scientists have investigated the occurrence of a great number of amino acids in protein from various parts of the whale body. They encountered large amounts of glycine, proline, hydroxyproline, and hydroxylysine in most internal organs (Nakai, 1959).

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CHAPTER 2, PART II

Shellfish Protein—Nutritive Aspects

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I. Introduction

Since time immemorial shellfish has been an important source of human nutrition. The molluscan shellfish probably antedates all other foods in this respect. The tremendous waste-heaps of primitive tribes—

coastal American Indians, Swiss lake dwellers, Scandinavian and Siberian fur settlers—predominatingly contain shells of oysters, mussels, etc. The long empirical traditions, therefore, bear strong evidence of the special merits of this group of aquatic organisms.

Modern nutritional science has given much support to this evaluation. Innumerable publications are available giving one or another contribution to a broadened knowledge of the nutritive values of both crustacean and molluscan shellfish and also revealing the limitations and particular assets of special groups. Notwithstanding, shellfish have not received the attention they deserve on the part of most nutritionists. Very few broad and penetrating studies are available pertaining to any major group. Nevertheless, the present fragmentary information permits some conclusions of general validity and, in other cases, the reviewing may have the function of spotting inadequacies and inconsistencies.

One complication was encountered in preparing this review. Unfortunately, the word fish is not infrequently used to cover all aquatic organisms eaten as food, inclusive of shellfish. It was not possible to go through all the studies which convey pertinent information on shellfish. There is, therefore, the obvious risk that some essential material and important information may be missing. This is particularly true insofar as abstracters or reviewers only occasionally index such information under the specific headings of shellfish, crustaceans, mollusks, shrimp, oysters or mussels, etc.

II. Protein Content

A. General

As a whole, the muscle tissue of shellfish usually ranges lower than that of most fish in total protein content; the crustaceans generally rate highest (27.1–22.0%), followed by the mollusks. In this latter case, mussels and squids (12.0%, 9.8%) rank higher than gastropods (9.9%). Exceptions seem to be the large squid "jubia," eaten in Spain, and with a protein content of 15.7% (Ferreyra Risso, 1953), and the Japanese earshell (see Table I)—24.6%. These general rules were confirmed by Intengan *et al.* (1956), who found that crustaceans in general had a protein content equivalent to that of fish, while, on the average, molluscan shellfish give values half as large. Some selected figures further illustrate these generalizations (Table II). Table III constitutes a selection of papers giving data on the protein content of various shellfish—see also the comprehensive bibliography by Van der Rijst (1950).

On a dry basis, the often-quoted figures are 85–88% for crustaceans and 44–49% for mollusks such as oysters (Lee and Pepper, 1956). The

Table I

Approximate Composition of the Meat of Selected Marine Animals[a]

Marine animal	Crude protein (%)	Marine animal	Crude protein (%)
Ear-shell	24.6	Whale (red meat)	21.0
Octopus	17.1	Dolphin	16.8
Oyster	13.1	Herring	14.6
Clam	11.3	Cod	16.9
Sea cucumber			
January	6.5		
August	7.7		

[a] Source: Tanikawa and Yoshitani, 1955.

Table II

Protein Percentage in Selected Shellfish

Species	Latin name	Protein (total N × 6.25)	Source
Crustaceans			
Crab	*Cancer pagurus*	22.4	Reay *et al.*, 1946
	Chionectes phalangium	19.4	Hatakoshi, 1932
Lobster	*Homarus vulgaris*	19.7–20.7	Reay *et al.*, 1946
Prawn	*Leander serratus*	22.8	Reay *et al.*, 1946
Shrimp	*Crangon vulgaris*	22.0–23.2	Reay *et al.*, 1946
Mollusks			
Oyster	*Ostrea edulis*	8.6–12.6	Krvarič, 1953
Mussel	*Mytilus edulis*	8.9–11.7	Reay *et al.*, 1946
	Mytilus munahuensis	11.3–19.4	Reay *et al.*, 1946
	Enoplochiton niger	24.7	Nexci Alferrano, 1954
Scallop	*Pecten maximus*	17.5	Reay *et al.*, 1946
Whelk	*Buccinum undatum*	17.5	Reay *et al.*, 1946
Winkle	*Littorina littorea*	18.0	Reay *et al.*, 1946
Cockle	*Cardium edule*	13.2	Reay *et al.*, 1946
Squid	*Loligo vulgaris*	14.9–19.3	de Gouveia and de Gouveia, 1951
Octopus	*Octopus vulgaris*	17.9	Saavedra, 1949

Spanish crab (*Polybius henslowi*) has, however, a low value of 44.2% (Varela and Pujol, 1956). A Mexican paste made of crustacean larvae and partially dried is a potent protein source—55.5%

B. Crustaceans

Crustaceans range in protein content from 9.4 to 15.3%, according to Carteni and Aloj (1934). Most analytical data in numerous food composition lists do, however, give higher values, listing crustaceans such as crabs, lobsters, shrimp, in the same range as mammal meat, or even higher—22–17%. This discrepancy could be due to the fact that tables

TABLE III
REFERENCES TO STUDIES ON PROTEIN CONTENT OF SHELLFISH FLESH

Shellfish	Country	Reference
A. Crustaceans		
Miscellaneous	Greenland	Hjarde *et al.*, 1952
	Italy	Lajtha, 1949
	Netherlands	Havinga, 1959
	Pakistan	Waheed Khan and Chughtal, 1956
	Peru	Velasco, 1946
	Spain	Charro Arias and Vaamonde, 1942
		Lopez-Bonito, 1955
	United States	Lee, 1935
		Nilson, 1943
Crabs	United States	Fellers and Parks, 1926
		Lanham *et al.*, 1940
	United Kingdom	Harry, 1936
Callinectes sp.	United States	Watson and Fellers, 1935
Chionectes sp.	Japan	Hatakoshi, 1932
Paralithodes sp.	Japan	Matsui, 1916
		Kondo and Iwamae, 1932
Platyonichus sp.	United States	Watson and Fellers, 1935
Polybius sp.	Spain	Varela and Pujol, 1956
Prawns and shrimps	United Kingdom	Harry, 1936
Five species	India	Shaikhmahmud and Magar, 1957
Cancer sp.	Peru	de la Torre, 1952
Palinurus sp.	Italy	Carteni and Aloj, 1934
Bithynis sp.	Peru	de la Torre, 1952
Peneus sp.	Italy	Carteni and Aloj, 1934
Lobster	United Kingdom	Harry, 1936
Crayfish	United Kingdom	Harry, 1936
B. Mollusks		
Miscellaneous	Greenland	Hjarde *et al.*, 1952
	Italy	Lajtha, 1949
	Netherlands	Havinga, 1959
	Pakistan	Waheed Khan and Chughtal, 1956
	Spain (Vigo)	Lopez-Bonito, 1955
	United States	Nilson, 1943
Gastropoda (snails)		
Helix sp.	Mexico	Villadelmar *et al.*, 1956–1957
	Peru	Vásquez Castillo, 1953
Pelecypoda		
Mussels		
Donax sp.	Brazil	Veloso *et al.*, 1951
Enoplochiton sp.	Peru	Nexci Alferrano, 1954
Mytilus sp.	Brazil	de Sigueira *et al.*, 1954
		Tobias e Silva, 1955
	Italy	Carteni and Aloj, 1934
		del Monte and Gambettii, 1959

TABLE III (*continued*)

Shellfish	Country	Reference
B. Mollusks (*continued*)		
	Netherlands	van de Velde, 1939
		Gerritsen and van Pelt, 1943
Solen sp.	Italy	Carteni and Aloj, 1934
Venus sp.	Italy	Carteni and Aloj, 1934
Clams		
Meretrix sp.	India	Venkataraman and Chari, 1951
Oysters		
Miscellaneous	India	Venkataraman and Chari, 1951
	New Zealand	Malcolm, 1927
Ostrea sp.	Japan	Masumoto *et al.*, 1932
		Hatanaka, 1940
	Portugal	de Gouveia and de Gouveia, 1951
	Yugoslavia	Krvarič, 1953
Crassostrea sp.	United States	Lee and Pepper, 1956
Scallops	United States	Bell, 1937
Cephalopoda		
Loligo sp.	Italy	Carteni and Aloj, 1934
		Carteni and Morelli, 1936a
	Peru	Ferreyra Risso, 1953
	Mexico	Villadelmar *et al.*, 1956–1957
	Portugal	de Gouveia and de Gouveia, 1951
Octopus sp.	Italy	Carteni and Aloj, 1934
		Carteni and Morelli, 1936
	Peru	Saavedra, 1949
	Mexico	Villadelmar *et al.*, 1956–1957
Sepia sp.	Italy	Carteni and Aloj, 1934

on food composition frequently give the values referring to edible or eaten protein, while published individual papers have taken the entire soft part of the body into account. Busson *et al.* (1953) list crab, together with tuna, as the food with the highest protein content (for the former, 21%).

Dried Bombay prawns of five different species show varying content of protein, 66.1–51.3% (Shaikhmahmud and Magar, 1957).

C. MOLLUSKS

Eight different mollusks were analyzed by Carteni and Aloj (1934) and showed a protein range of 8.4 to 14.0%. As mentioned above, the Japanese ear-shell is exceptionally high—24.7%. So is a Peruvian mussel (*Enoplochiton niger*), with the same high value (Nexci Alferrano, 1954). This recommends it highly as food, particularly as its nutritive value is also high.

A differentiation should be made between the body liquid of the mussels and the body tissues as such. The liquid of oysters is quite rich in organics, albumins (2 g./liter), peptides, and mucin (Baylac, 1907).

Scallops contain less protein than beef, lamb, chicken, or fish, according to Bell's investigations (1937).

The octopus stands high in protent content—17.9% according to Peruvian analyses (Saavedra, 1949). On the other hand, Ferreyra Risso (1953) considered cephalopods largely as having lower protein figures than crustaceans.

Taxonomically, the cephalopods are subdivided into cuttlefish, carrying the cuttle bone, squids, and octopi. They are all used as food in various parts of the world. It is deplorable that these three major groups are not always kept apart in nutritional studies. Frequently they are used synonymously or are not correctly categorized.

The general composition of squid protein as to myosins and their characteristics was investigated by Matsumoto (1958). Their protein resembles that of fishes with certain distinctive features.

As a whole, shellfish are equal to fish in protein content, but a few contain even more protein than do fish. Several molluscan shellfish, particularly gastropods, are appreciably lower in protein than fish. See Table I.

D. Meat Content

In several shellfish, more than the muscle tissues are eaten. What is termed meat is not always identical to the flesh in other animals. This has to be borne in mind when evaluating analytical data. The shells, nevertheless, constitute a major portion of the live weight (see Table IV), more so in mollusks than in crustaceans.

Table IV
Edible Content of Major Shellfish[a]

Shellfish	No. of samples	Edible portion (% of weight in shell)
Crustaceans		
Crab	4	40
Lobster	3	44
Prawn	1	46
Shrimp	1	47
Mollusks		
Oyster	42	11.8
Mussel	2	28
Scallop	1	18
Whelk	1	42
Periwinkle	1	22

[a] Source: Reay *et al.*, 1946.

The meat content of Japanese oysters shows a sexual difference (Masumoto *et al.*, 1932). Females have 30% more meat and twice as much fat.

E. Seasonal Changes

The composition of both crustacean and molluscan shellfish varies with season and particularly with the spawning time. Fat and protein generally build up to this major event, after which they drop.

In oysters the proportion of glycogen to protein is approximately reciprocal (Hatanaka, 1940). The energy content varies only slightly, attaining a maximum in late fall and early winter, with some differences between species (Masumoto *et al.*, 1932, 1934; Tully, 1936; Krvarič, 1953).

The protein percentage increases in the spring and remains constant throughout the summer, but drops in the late fall (Krvarič, 1953).

Japanese oysters do not show the winter loss in weight and in protein (Sekine *et al.*, 1929; Masumoto *et al.*, 1932), probably because feeding is not arrested during the winter to the same extent as in Atlantic waters (Tully, 1936). The protein peak appears in the late summer in Pacific oysters, which appears to differentiate them from the Atlantic species.

The common blue mussel from the Vigo estuary shows a maximum amount of protein (13.4%) in the fall but a minimum (9.2%) in the spring in February (Fraga, 1958). With the scallop, the situation is almost the reverse: in the last half of April the protein figure reaches a peak and passes its maximum in the last half of November (López-Bonito, 1955).

Important, too, is the relationship between fat content and protein. In the scallop, this ratio has a maximum in February and a minimum in June.

In the oyster, there is a maximum in meat content, reached in December, and a minimum in January. A second maximum comes in March, after which there is a rapid decline to a second minimum in July. The protein content closely follows this same pattern, while glycogen shows the opposite trend. Recovery takes place in early autumn, where there is more plankton in the sea, as shown in the figures in the tabulation (gram on the average per individual).

	Total weight	Water	Solids	Lipids	Protein	Glycogen
Loss between June and July	5.6	4.7	0.912	0.178	0.473	0.037
Gain between September and October	6.3	4.7	1.602	0.100	0.606	0.219

Protein accounts for more than half of the loss as well as one-third of the gain (Sekine *et al.,* 1930).

F. OTHER INVERTEBRATES

Sea cucumber flesh, as Table I indicates, has a protein content which is only one-third that of fish meat. Therefore, it is not looked upon as a protein source (Tanikawa, 1955), even though its aminogram compares well with that of fish meat. It may, however, have certain other merits revealed through recent research (see Section G).

The chemical composition of the meat of a sea cucumber (*Stichopus japonicus*) commonly eaten in Japan varies with the season. The water content (86–92% throughout the year) is greater than that of fish meat, which shows 75–85%. The amount of protein in the flesh grows, together with that of fat, from September to January and then drops in the period from February to May (Tanikawa, 1955).

Squid meat is composed of a more water-soluble protein than that of fish meat. Sea cucumbers show the opposite characteristic, having chiefly insoluble protein, viz., collagen, which dissolves in water only with difficulty. There is, however, some soluble protein in the network of the connective tissue (Tanikawa, 1955).

The edible part of the body of *Stichopus japonicus*—the body wall—is histologically not muscular tissue, but consists mainly of connective tissue, built into a network of collagen fibers. The amount of collagen in the meat protein is about three times that in fish meat. In this structure the fibers are encased body-fluid-carrying soluble proteins, e.g., myosin and myogen. The hydrating affinity of the meat is inferior to that of fish meat. Only a minor portion of the water is bound water. Therefore, the body of *Stichopus japonicus,* when left in a basket, loses a major portion of its water (Tanikawa, 1955).

G. GENERAL COMPOSITION

A few studies are available on the general composition of shellfish protein. In myosin solubility, lobster protein comes closest to that of the rabbit (Dubuisson-Brouha, 1953). Whereas the water-soluble proteins and nonmyosins of several fishes were equal in amount, the water-soluble protein of squid (77–85%) constituted a far greater percentage than the amount of nonmyosin (12–20%) (Matsumoto, 1955, 1958). Although the muscle protein of squid resembles that of fish, the properties of its myosins are distinct.

Crustacean proteins frequently are bound to sugars forming glucoproteins. Lobster protein contains 2.2% sugars, consisting of three parts glucose and eight parts of fructose, while crab protein has 2.8% sugars in a ratio of four parts glucose to one part fructose (Kondo and Sarata, 1940).

The meat of *Stichopus japonicus* contains a large quantity of mucoprotein with chondroitin sulfuric acid as a component. In the studies of geriatrics the relation between the superannuating phenomena of muscle tissue and the decreasing of chondroitin sulfuric acid has been indicated. The Chinese have been eating sea cucumber since ancient days; this biochemical relationship might explain its popularity (Tanikawa, 1955).

The swelling, or the degree of hydration, of a protein shows a minimum at the isoelectric point, and increases to either side, acid or alkaline. This was demonstrated for fish by Tarr (1942), Noguchi *et al.* (1950), and Okada and Tada (1953, 1954). Takahashi (1955) showed the same effect with collagen. The swelling of fish meat has a minimum value at the isoelectric point (pH 4–5) and a maximum value at either the alkaline side (pH 10–12) or the acid one (pH 2–3). In the presence of salts, the swelling is enhanced on the alkaline side, but is reduced on the acid side (Tarr, 1942, and Okada). Meat of sea cucumbers shows no peak of protein swelling in acid solution as does that of fish (Tanikawa, 1955).

The flesh of sea cucumbers shrinks rapidly when immersed in water at temperatures between 45° and 55°C. and contracts about 50% at 70° to 80°C. In this respect it resembles the collagen-rich fish skin (Takahashi, 1955), which shrinks in the temperature range of 37° to 55°C. Fish meat shows a peak of swelling on both sides of the isoelectric point (pH 4–5). Sea cucumber differs in this respect, with no maximum in hydration in the acid region (Tanikawa, 1955). This may be explained by the aforementioned high content of collagen.

III. Biological Value

Jones (1926) found the ratio values of (gain in weight)/(gram of protein) for shrimp, clam, and oyster to be 2.2, 2.1, and 1.3, respectively. Lanham and Lemon (1938) established values (see tabulation) for the relative growth-promoting effect. Both oyster and shrimp exhibit good nutritive value.

100	90	80	63
Oyster	Shrimp Pilchard Red snapper	Cod Shad	Beef

Crab protein tested for the growth effect on experimental rats was superior to casein. Its biological value was on the same level as beef

(Watson and Fellers, 1935). Prawn protein had a good biological value (74) but lower than that of hake (Pujol and Varela, 1958).

The "patexo" (*Polybius henslowi* Leach) is a crustacean, abundant during certain months along the Galician coast of Spain. Dried, it is used as a meal. The biological value of its protein is low. Even negative values were obtained in rat experiments (Varela and Pujol, 1958).

The oyster is outstanding as one of the marine proteins best suited to man—conforming to his specific requirements in this respect. This explains its use in therapeutic diets (Le Gall, 1948). Oyster protein was superior to that of seven fish studied, and surpassed shrimp. Beef was inferior when measured by the effect of extracted proteins on rat growth (protein efficiency ratio) (Lanham and Lemon, 1938). In the brackish lakes of the coastal regions of Brazil, the Brazilian mussel (*Mytilus manuhuensis*) is commonly eaten by the poor. Its protein is equal to casein in nutritive value (de Sigueira *et al.*, 1954). Along the Peruvian coast is found another mussel (*Enoplochiton niger*)—"barquillo"—with a high protein content (24.7%) and of superior quality, as measured in experimental growth studies (Nexci Alfersano, 1954).

Flesh of a kind of cuttlefish ("variika") and crab ("tara bagani"), when tested against the proteins of horse, whale, and fish as to their effect on the normal growth curve of rats, compared favorably (Suzuki *et al.*, 1912).

IV. Amino Acid Composition

A. GENERAL

Shellfish muscle tissue is generally characterized by its high content of nonprotein nitrogen (Campbell, 1934–1935). In the first and second decade of this century, a breakdown of the shellfish proteins through hydrolysis was done experimentally, together with similar analyses of other flesh tissues used as food (see Part I of this chapter). The close similarities between shellfish protein and that of other flesh products, whether vertebrate or invertebrate, were noted. Within these "two groups" deviations were few. Furthermore, shellfish protein, whether crustacean or molluscan, is composed of much the same constituents (Beach *et al.*, 1943; Duchâteau *et al.*, 1959) (see Table V). Leont'ev and Markova (1936) reported that the curves for racemization of proteins from major proteins of invertebrates were almost identical, thus constituting an indirect evidence of their similarity. This contrasts with the specific character of the pool of free amino acids. Differences in the proteins presumably exist in their molecular build-up. A list of studies from various parts of the world on the amino acid composition of shellfish is given in Table VI.

TABLE V

PER CENT CONTRIBUTION OF AMINO ACIDS TO TOTAL NITROGEN OF SELECTED PROTEINS FROM MUSCLE TISSUE[a]

Food	Arginine	Histidine	Lysine	Phenylalanine	Tyrosine	Tryptophan	Serine	Threonine	Cystine[b]	Methionine
Pork	13.3	3.7	10.4	2.1	2.1	1.1	3.8	3.4	0.7	1.9
Chicken (white flesh)	13.9	4.0	10.1	2.0	2.1	1.1	3.9	3.4	0.6	2.0
Codfish	12.6	3.5	10.1	2.3	2.2	1.1	4.1	3.3	0.8	2.2
Shrimp	13.2	3.1	10.0	2.5	2.3	1.1	3.3	2.9	0.7	2.0

[a] Source: Beach *et al.*, 1943.

[b] The Sullivan method.

Scallops, fresh-water crayfish, and sea cucumbers all have an amino acid composition making their protein fully comparable to casein (Leont'ev and Markova, 1936).

TABLE VI
STUDIES FROM VARIOUS PARTS OF THE WORLD ON AMINO ACID COMPOSITION OF SHELLFISH

Shellfish	Region	Source
Crustacean		
Lobster	Soviet Union	Taranova *et al.*, 1955
	India	Airan *et al.*, 1953
Shrimp	India	Sarkar and Raha, 1954
Scylla sp.	India	Airan and Karat, 1953
Chionectes sp.	Japan	Hatakoshi, 1932
Palinurus sp.	Japan	Okuda *et al.*, 1919
Paralithodes sp.	Japan	Okuda *et al.*, 1919
Peneus sp.	Japan	Kondo and Iwamae, 1932
	United States	Jones *et al.*, 1925
	Mexico	Bachstez and Bustamente, 1955
Crabs	Germany	Röhrig, 1905
		Ackermann and Kutscher, 1907
	Soviet Union	Taranova *et al.*, 1955
Grapsus sp.	China	Kuo-Hao, 1926
Crayfish	Soviet Union	Leont'ev and Markova, 1936
Molluscan		
Miscellaneous	United Kingdom	Potts, 1958
Mussels		
Anodonta sp.	United Kingdom	Potts, 1958
Mytilus sp.	United Kingdom	Potts, 1958
Scallops		
Pecten	Soviet Union	Leont'ev and Markova, 1936
Cephalopods		
Loligo	Japan	Okuda *et al.*, 1919
Ommastrystes sp.	Japan	Kōnosu *et al.*, 1957
Squid	Japan	Sugimura *et al.*, 1954
Oysters	Belgium	Duchâteau *et al.*, 1952
	Spain	Intengan *et al.*, 1956
	Yugoslavia	Krvarič, 1953
Gastropods		
Thais sp.	Peru	Okuyama Bazan, 1953
	Soviet Union	Leont'ev and Markova, 1936
Stichopus sp.	Japan	Tanikawa and Ichiko, 1955

Crustacean protein is purported to show less tyrosine, arginine, and methionine than mammal protein does (Malikova, 1957).

Molluscan proteins showed lower values for valine, methionine, phenylalanine, lysine, and histidine than the muscle proteins of fish and crustaceans (Kōnosu and Mori, 1959). These observations were based on hard clams and abalone.

Both methionine and threonine were found to be lower (30–40% less) in both crustacean and molluscan shellfish as compared to most fish, both salt-water and fresh-water species (Hatakoshi, 1953).

B. CRUSTACEANS

Crustacean protein compares well in major amino acids with casein, beef, and egg albumen (Pottinger and Baldwin, 1940; Master and Magar, 1954).

The pattern of amino acid distribution in crustacean protein is relatively uniform (Kuo-Hao, 1926). Some slight differences, however, were observed (Kōnosu *et al.*, 1958) (see also Tables V and VII). The amount of arginine is the most variable, ranging between 6.3% (blue crab) and 9.0% (prawn). The content of glycine, alanine, leucine, tyrosine, and phenylalanine of crustacean muscle proteins was at almost the same level as those of the ordinary muscle protein of fish. But the crustacean muscle shows a higher value of the acidic amino acids, glutamic and aspartic acids, and a lower value of valine, isoleucine, threonine, and lysine when compared with fish muscle (Table VIII). Master and Magar (1954) found no difference in lysine, nor did Taranova *et al.* (1955). Kuo-Hao (1926) obtained high lysine values in crabs, as did Kondo and Iwama (1932).

TABLE VII

AMINO ACID COMPOSITION OF SHELLFISH[a]

Amino acid	Prawn	Lobster	Blue crab	Fish
Glycine	4.7	4.6	4.7	3.0–5.5
Alanine	6.0	5.9	5.7	5.1–7.3
Valine	4.4	4.5	5.0	5.6–9.3
Leucine	8.6	8.6	9.0	7.4–9.4
Isoleucine	3.8	4.1	4.7	5.0–7.9
Serine	4.2	4.9	4.9	4.6–5.5
Threonine	4.1	4.4	5.2	5.2–6.0
Methionine	2.8	3.2	3.0	3.1–3.7
Cystine	1.10	1.3	1.7	—
Aspartic acid	11.7	12.3	12.0	6.2–11.5
Glutamic acid	17.5	16.9	16.2	13.4–16.9
Tyrosine	4.1	4.1	4.7	3.5–4.6
Phenylalanine	4.4	4.7	4.8	3.4–5.2
Proline	3.7	3.4	4.5	2.9–4.2
Tryptophan	1.0	0.9	1.6	1.1–1.4
Arginine	9.0	7.4	6.3	5.9–6.9
Lysine	9.4	9.5	8.9	9.9–11.8
Histidine	1.9	2.1	2.4	2.2–3.9

[a] Source: Kōnosu *et al.*, 1958.

The histidine-arginine fraction is generally very high in crustacean shellfish (Kondo and Iwamae, 1932; Campbell, 1934–1935). Soviet studies found arginine and cystine higher in lobster and crab, exceeding the values for most fish and terrestrial meats.

TABLE VIII

AMINO ACID COMPOSITION OF BOMBAY CRUSTACEANS[a]

Grams per 100 g. of protein calculated to 16% N.

Amino acids	Prawn	Lobster	Fish ("pakat")
Methionine	4.6	2.2	1.6
Lysine	18.5	17.6	19.5
Phenylalanine	4.6	2.7	2.7
Histidine	1.6	1.2	1.7
Leucine	14.3	11.3	12.5
Valine	4.1	2.9	3.5
Isoleucine	5.6	4.3	5.2
Cystine	1.4	1.5	1.0
Arginine	8.3	7.2	5.2
Threonine	4.6	5.3	4.6
Tryptophan	0.4	0.2	0.6
Tyrosine	1.0	0.8	1.4

[a] Source: Master and Magar, 1954.

The Indian prawn "pak" has a good aminogram and is readily digested (Valanju and Sohonie, 1957); in fact, it exceeds casein in this respect.

The crustacean flesh (shrimp, lobster, crab, and crayfish), as well as that of mollusks, is practically devoid of creatine. Related compounds are found in place of creatine, e.g., in crustaceans the amino acid arginine which combines with phosphorus.

C. MOLLUSCAN SHELLFISH

The first amino acid analysis reported was on a scallop. Chittenden (1875) found in the major adductor muscle of *Pecten irradians* a relatively large amount of free glycocoll. But Osborne and Jones (1909) found still more when analyzing the protein. The general amino acid composition of scallop protein closely resembled that of halibut and chicken. There was somewhat less of leucine and slightly more of phenylalanine and arginine.

Kōnosu and Mori (1959) compared the amino acid distribution of the proteins in the minced edible part of a hard clam (*Meretrix meretrix lusoria* Gmelin) with that of an abalone (*Haliotis gigantea* Gmelin), and found that they were rather uniform, but some slight differences were observed. The protein of abalone is richer in glycine, proline, and arginine, but poorer in leucine, glutamic acid, tyrosine, and lysine. It was also found that the tryptophan content of the hard clam protein is higher. These molluscan proteins show a lower value of valine, methionine, phenylalanine, lysine, and histidine than the muscle proteins of fish and crustaceans examined in previous studies (Kōnosu and Mori, 1959).

D. CEPHALOPODS

Kōnosu *et al.* (1956, 1957) established that the content of essential amino acids in cuttlefish protein coincides greatly with that of teleost fish.

Squid contained larger amounts of arginine, aspartic acid, glutamic acid, and leucine and exceeded most vertebrates in this respect (Sugimura *et al.*, 1954) but was lower in histidine, lysine, and methionine. No differences were observed in other amino acids. It can be seen in Table IX that the content of lysine in squid not always is superior to that in fish.

TABLE IX
COMPARATIVE NITROGEN DISTRIBUTION IN VARIOUS FISH AND SHELLFISH MEAT[a]
(calculated as % of total N)

Nitrogen	Squid	Octopus	Sea cucumber	Sardine
Total (dry matter)	12.6	15.6	9.5	13.3
Amide	4.1	4.3	3.4	6.4
Humin	3.3	1.5	11.5	1.2
Arginine	20.0	17.1	11.2	11.9
Histidine	8.7	4.9	9.4	0.4
Lysine	10.1	9.4	0.8	15.0
Cystine	0.9	0.6	0.9	0.2

[a] Source: Tanikawa, 1955.

E. MISCELLANEOUS INVERTEBRATES

The sea cucumber is characterized by high histidine values, but is very low in lysine and cystine (Table IX).

A compound toxic to protozoans, certain amphibia, fish, and mice was discovered in a sea cucumber common in the Caribbean, *Actinopyga agassizi.* It was named holothurin (Nigrelli and Zahl, 1952).

F. SULFUROUS AMINO ACIDS

Okuda and Matsui (1916) reported that the sulfur content of crustacean flesh is higher than that in fish (1.2–2.8% sulfur in dried fish). Female crabs contain more sulfur. The sulfur in shrimp protein was studied in 1932 by Baernstein, its amount being only slightly higher than in halibut flesh.

Methionine, cystine, and cysteine were analyzed in four crustaceans from off the Peruvian coast. Both methionine (0.6–0.36%) and cystine

(0.52–0.26%) were high, while cysteine was low (0.12–0.06%) (de la Torre, 1952). Later, molluscan shellfish were investigated as to these same constituents, showing in broad lines a similar pattern. Squids, octopi, and mussels were studied also (Flores Castañon, 1953).

Cysteine and cystine are absent in shrimp, according to Ranke (1959).

Both crustacean and mollusks are rich in methionine. Squids and dried crustacean paste are high in methionine—approximately 3.2% of the protein, according to Villadelmar (1956–1957) (see tabulation).

	Methionine content (% of protein)	Source
Oyster (Japanese)	0.25	Ogata, 1951–1952
Meretrix sp.	2.18	Ogata, 1951–1952
Mactura sulcatria	3.46	Ogata, 1951–1952
Squid	3.2	Villadelmar, 1956–1957

G. Lysine

Lysine was reported higher in shrimp than in scallop muscles (7.7% as against 5.8%) (Jones *et al.*, 1925). In general, crustacean protein is high in this important acid (Master and Magar, 1954).

Most shellfish used in Mexican diets are rich in lysine; 9.2–10.2%, according to Villadelmar (1956–1957). Sea cucumbers are poor sources of lysine (Tanikawa, 1955).

H. Tryptophan

Blue crab contains 1.6% of tryptophan. This value is the highest encountered in any fish or crustacean (Kōnosu *et al.*, 1956).

The content of tryptophan is higher in squids and snails than in blue crab (Villadelmar *et al.*, 1956–1957). This was shown to be true for the large squid *Loligo gahi* (Ferreyra Risso, 1953).

I. Tyrosine

The large squid *Loligo gahi,* commonly eaten in Spain, is higher in tyrosine than most fish, namely, 0.39% of the flesh or about 2% on a dry basis (Ferreyra Risso, 1953).

J. Glutamic Acid

Shellfish generally is as rich in glutamic acid as wheat flour, and consequently is a good source (Reyes, 1950). It exceeds most fish, although shellfish generally contain more of this amino acid than beef does.

K. Free Amino Acids

The first study on free amino acids was conducted on crabs (Ackermann and Kutscher, 1907; Suzuki, *et al.*, 1912). In 1909, Suzuki and Yoshimura reported on free amino acids in lobster and squid. Okuda (1912) and Okuda *et al.* (1919) concluded that shellfish muscle is characterized by the lack of creatine, whereas vertebrates, including fish, commonly carry this compound. This was confirmed in later investigations (Campbell, 1934–1935; Fraser *et al.*, 1952).

Arginine shows the reverse pattern, being abundant in extracts of shellfish, both crustacean and molluscan, but lacking in vertebrate muscle tissue. It is, however, present in large quantities in the muscle protein of both vertebrates and invertebrates. Arginine unquestionably is the mother substance of creatine. This leads to the conclusion that vertebrate tissues have the power to transform arginine into creatine, while the invertebrates lack this capability.

When comparing the free amino acid pool of a gastropod, Chinese crab, and lobster, certain specific characteristics were noticed for each of these, in spite of the fact that they all carried the same fifteen amino acids (Camien *et al.*, 1951; Florkin, 1954; Duchâteau *et al.*, 1954). The muscle protein does not change its composition parallel with variations in the free pool. Lobster flesh has a protein with a higher content of arginine, glycocoll, and proline, while the muscle protein of the snail is dominated by alanine and arginine.

Free amino acids and other similar compounds play an important part in the osmotic regulation of marine invertebrates. This has been confirmed for the whole muscle of *Nephrops* (Robertson, 1957) and for *Carcinus*, where they account for over 60% of the total osmotic activity (Shaw, 1958). Fraser *et al.* (1952) reported that the principal free amino acids in the flesh of lobster and crabs were proline, glycine, and the related taurine, with less glutamic acid and asparagine. An unidentified amino acid was found by Airan *et al.* (1953) in studies on East Indian lobsters.

Nonprotein nitrogen as a whole constitutes about 10% of the total N in teleosts, 20% in crustaceans and mollusks, and 30% in the elasmobranchs. Levels of free amino acids N was 300 mg./100 g. of wet muscle in crustaceans and mollusks, while in fish it was 20–40 mg./100 g. wet muscle (Velankar and Goindau, 1958b) (see Chapter 11 by Simidu in Volume I).

The fifteen nonprotein amino acids present in the flesh of crustaceans occur in higher concentrations in marine forms than in fresh-water species. Among the latter, the Chinese crab *Eriocheir sinensis* is a poekilo-osmotic form which exhibits concentration changes depending on the external environmental waters (Edwards *et al.*, 1955; Florkin, 1958–1959). In sea water the concentration is higher, in particular in proline and all other amino acids, with the exception or arginine. These animals return to their original concentration in fresh water as soon as they are returned to such an environment. The species belonging to a brackish form acquires a concentration in between that of fresh and marine waters. There have been indications that the pool of free amino acids plays a role in osmotic regulation of the tissue. The ordinary fresh-water crayfish, however, which is not adapted to living in brackish water, does not show the same changes in water with a salt concentration half that of marine water; only the protein content is increased. The free amino acids remain unchanged (Duchâteau and Florkin, 1954, 1955a, b, 1956). This entire field of environmental effects on the composition of the pool of free amino acids has recently been reviewed by Waterman (1960).

Seventeen free amino acids were found in the muscles of three kinds of mollusks, the clam (*Meretrix meretrix lusoria*), the little-neck clam (*Tapes japonica*), and the soft-shelled clam (*Mya japonica*), and their variations during spoilage were determined by the microbiological method. For the purpose of comparison, the same determination was made on the muscle of the mullet (*Liza haematocheila*). The amino acid nitrogen accounted for about 52 to 63% of the extractive nitrogen in the molluscans, but only 29% of the mullet. The main components of the free amino acids were alanine, glycine, arginine, and glutamic acid in the muscle of three shellfish, while in the fish they were glycine, histidine, and alanine (Ito, 1959).

Iced shrimps (and prawns) lose amino acids through leaching for 6 to 7 days. This in turn explains the reduced flavor (Velankar and Govindan, 1958a). Naturally, these losses may contribute to a somewhat lower supplementary value of these products.

True *arginine* was discovered in lobster muscle by Hoppe-Seyler (1933) in the D-form, not as the DL-form, which was earlier obtained from fresh-water crabs by Broude (1933). Kermack *et al.* (1955) encountered large amounts of free proline and glycine in fresh lobster muscle, smaller quantities of glutamine and alanine, and traces of aspartic acid, glutamic acid, histidine, lysine, threonine, and tyrosine. Camien *et al.* (1951) found somewhat more arginine, and less valine and leucine. In addition, Kermack *et al.* (1955) found taurine present to the extent of about 300 mg./100 g. wet muscle. The relatively small amount of histidine present is in striking contrast to the amount of this amino acid found in certain fish, particularly those with red meat.

Free *glycine* was detected early by Chittenden (1875) in scallops (*Pecten irradians*) and later by Kelly (1904) in *P. operculans.* It generally coexists with betaine. Large quantities have been demonstrated in starfish.

Proline is the mother substance of stachydine and has been found in lobster, squid, and shrimp.

Taurine is a common constituent of many kinds of muscles, and is not limited to molluscans, as some authors maintain, although the quantity predominates there. Shellfish are consequently richer than most fish in this particular compound (Okuda and Sanada, 1919) (see tabulation).

Shellfish	Taurine in % of fresh flesh	Taurine in % of dry flesh
Crustacea		
Neptunus pelagicus	0.3	1.4
Palinurus vulgaris	0.2	0.8
Mollusks		
Pinna japonica (adductor muscle)	0.5	2.4
Avicula martensii (mantle)	0.9	5.2

Source: Okuda and Sanada, 1919.

Kelly (1904) estimated that taurine made up 5% of the dry matter of *Mytilus* muscle, corresponding to 100 millimoles/kg. water in the whole muscle. Arginine and taurine were identified in the marine gastropod *Patella* (Ackermann and Janka, 1954).

The concentration of amino acids in the salt-water *Mytilus* blood is only 2.5 millimoles/kg. water, but is lower, 0.5 millimole/kg. water in the fresh-water mussel *Anodonta.* Much higher values are encountered in the muscle tissue: in the *Mytilus* muscle 166.2 millimoles/kg. total water and in *Anodonta* 9.5 millimoles/kg. total water, but yet far less in the fresh-water forms (Duchâteau *et al.*, 1952).

L. OTHER SHELLFISH PRODUCTS

In comparing the protein of muscle tissue with the chitin of crustaceans, basic differences have been noted. Both tyrosine and cystine are lower in chitin, when compared to muscle tissue (Airan and Thomas, 1953). In some crustaceans no arginine or cystine was found in the chitin (Airan and Karat, 1953; Airan and Thomas, 1954).

Octopine, containing chiefly arginine, has been isolated from squids, octopi and scallop muscles. Its nutritive value has not been investigated. Further information on this and related compounds is available in Chapter 11, Volume I.

V. Other Nutrients

Most shellfish are rich in calcium (Malikova, 1957). Also nutritionally significant is the fact that thiaminase occurs in some shellfish, both molluscan and crustacean. Shrimps (*Peneus* sp.) and some mussels are rich in this enzyme, while it is almost absent in most crabs (Jacobsohn and Azevado, 1947). The presence of this enzyme induces abnormally low thiamine values in the muscle tissues of such shellfish after death (Lubitz *et al.*, 1943).

These factors may be important in the right interpretation of the biological and nutritive value of shellfish proteins.

VI. Digestibility

The digestibility coefficient of shrimp was found to be 67. The biological value of this protein was 69, and the net utilization coefficient 56. Thus, 1 kg. of shrimp meat yielded only 126 g. of fully utilizable protein. The corresponding figures for smoked cod flesh was 148 g. (Varela, 1955).

The digestibility of sea cucumber tissue is inferior to that of fish meat (Tanikawa, 1955).

In a comparative study covering fish and several shellfish, lobster consistently turned out to be the leading crustacean as to net utilization ratio (see Part I of this chapter) and digestibility. Octopus and ordinary mussel (*Mactra helvacea*) led in the molluscan group. Oyster was not tested. Squid is inferior to octopus (Pujol and Varela, 1958).

VII. Changes in Storage and Processing

A. SPOILAGE

The middle section of the intestines carries glands which excrete quite potent cathepsins. Independently of bacterial attacks, a proteolytic, rather rapid breakdown takes place in the vicinity of the viscera in the meat of crabs (Degkwitz *et al.*, 1954).

During spoilage, there is a continuous increase in the concentration of leucine, isoleucine, valine, glutamic acid, aspartic acid, α- and γ-aminobutyric acid (Ranke and Bromstedt, 1954; Ranke *et al.*, 1956), the two latter presumably being of a bacterial origin.

There are considerable changes among the free amino acids during spoilage. The total amount goes up as the mollusks spoil, the amount of free arginine falls rapidly, and glutamic acid decreases to some degree. Other amino acids increase slightly, but the change is not considerable (Ito, 1959).

Poisoning through mollusks constitutes a hazard. This is generally caused by toxic compounds emanating from dinoflagellates and is further discussed in Chapter 11 by Shewan. In other cases, mollusks may convey *Coli* and *Salmonella* infections. Large cleansing tanks with chlorinated water constitute an important countermeasure. In recent years there have been reports from Sweden, Mississippi, and New Jersey of oysters and clams having caused epidemics of hepatitis (Anonymous, 1961). These problems are further elaborated in Chapter 7 of this volume. A Japanese gastropod (*Nephenea arthritica*) carries a poisonous salivary gland which has to be removed prior to consumption (Asano, 1951–1952). Factors of this kind contribute to restrictions in the full use of shellfish as food.

Blackening of shrimp is due to enzyme activity, phenoloxidases forming melanins (Bailey, 1958). It has largely been overlooked that crustaceans can be subdivided biochemically into two major groups as to their hypodermic amino acids and their capability of forming melanin pigments (Drilhon and Busnel, 1950). The relative importance of individual free amino acids differs somewhat. In both groups, whether they can form melanin or not, glycocoll, alanine, and valine are the leading amino acids, but the composition becomes different when the acids are listed in order of importance:

Without melanins	With melanins
Tyrosine	Aspartic acid
Glutamic acid	Proline
Aspartic acid	
Leucine	
Histidine	
Proline	

For further discussion see Chapter 8, Volume I.

B. Freezing

Freezing had no effect on the nutritive value of crab proteins, according to Watson and Fellers (1935). The blue and the sand crab were studied.

C. Canning

In canning crab, the nutritive value of its protein was only very slightly reduced (Watson and Fellers, 1935). Both biological value and digestibility were largely maintained on a high level in the canning of blue crab, king crab and Dungeness crab (Lanham *et al.*, 1940). In a broad comparative study it was established that the heat processing employed in canning did not change the amino acid composition of shrimp (Dunn *et al.*, 1949; Nielands *et al.*, 1949).

Not infrequently, crab meat, when processed through canning, turns brown. This seems to occur at a high temperature when processed on land, but at a low temperature when prepared on floating canneries. Only when not completely fresh raw material is used does browning occur at high temperatures.

The low-temperature treatment may give browning discolorations even in meat from newly captured specimens. In both cases the browning is due to the traditional Maillard reaction, the presence of both amino acids and reducing sugar constituting prerequisites for such a reaction. Their amounts are generally larger in meat that browns than in normal packs. Browning is more often observed in canned products prepared from hard-shell crab than from peeled crab. Crabs kept in ice water showed less susceptibility than those held in crushed ice, presumably due to leaching.

The presence of Cu^{++} in crab blood (body fluid) or Fe^{+++} in crab meat accelerates the browning reaction. The greater the remaining amount of blood in the meat, the greater is the degree of browning (Nagasawa, 1960).

D. Cooking

Using the proteolytic breakdown through pancreatin as a test method, it was established by Nomura (1953) that shellfish protein was more readily digested in the raw stage than in the cooked forms. This is in accordance with findings on fish, but in contrast to poultry meat and beef.

Okuda and Matsui (1916) reported that, in cooking, some volatile sulfur compounds are formed in Kamchatka crabs. As female crab contains more sulfur, its flesh is considered inferior for canning. Free amino acids are lost in the cooking of shrimp (Ranke, 1959).

E. Drying

Dried flesh of a crab (*Polybius henslowi*) common to the northwest coast of Spain contained 44.2% of protein. Rat growth experiments showed that the digestibility coefficient of its protein was 78.7 but that the nutritive value was low.

The semidrying of prawns is a novel, more lenient method of preservation. Such semidried prawns retained all the essential amino acids (Chari and Venkataraman, 1957).

Dried mollusks, both fresh-water and salt-water species, are used as poultry feed. This product contains 59–76% protein with a good amino acid composition, but cystine is reported lacking (Zikeev, 1948). This particular amino acid is, however, readily synthesized by the hen.

Dried squid is a popular food in many countries. It is used as a base for soup stock. Normally this product maintains its protein quality well and also its stock of free amino acids. Yoshimatsu *et al.* (1958) reported the abundant presence of glycine, alanine, proline, and glutamic acid. Betaine is also a dominant ingredient.

The fresh meat of *Stichopus japonicus* is difficult to dry. The hydrating affinity of the sea cucumber meat is comparatively weak, but the meat nevertheless is very difficult to dry (Tanikawa and Yoshitani, 1955). This difficulty varies, depending on the drying temperature.

F. FERMENTATION

Soy sauce is not infrequently made from shellfish, particularly cephalopods, through autodigestion. In comparing such sauces made from octopus and squid, only minor differences were observed in the amino acid composition of the final products (Table X). This seems to be true of both total diamino and monoamino acids, as well as the individual major amino acids, such as arginine, lysine, and histidine (Fukai, 1947).

TABLE X
NITROGEN DISTRIBUTION IN FLESH OF CEPHALOPODS[a]

Acid-soluble N	Octopus %	Squid %
Amino	14.6	13.3
Humin	2.5	3.9
Arginine	9.4	10.9
Histidine	9.9	8.9
Lysine	10.6	10.6
Cystine	1.0	0.4
Total diamino	30.8	30.8
Total monoamino	52.4	52.7
Non-amino	4.9	1.3

[a] Source: Fukai, 1947.

G. HYDROLYZATES

Not only fish are fermented into pastes in Southeast Asia. Several shellfish are prepared the same way through a partial enzymic hydrolysis—about half of the protein is split into amino acids. Several such shellfish pastes are known from the Philippines, Cambodia, Laos, Indonesia, and Burma. The amino acid composition of the Burmese "ngapi seinsa" makes it nutritious human food (Blass and Richard, 1952; Duchâteau *et al.*, 1953)—see Table XI.

TABLE XI
AMINO ACIDS IN THE SHELLFISH PASTE "NGAPI SEINSA"[a]

Amino acid	% Dialyzable nitrogen	Amino acid	% Dialyzable nitrogen
Alanine	9.3	Lysine	8.4
Arginine	5.8	Methionine	1.3
Aspartic acid	5.6	Phenylalanine	2.3
Gutamic acid	8.8	Proline	2.0
Glycocoll	8.5	Threonine	2.7
Histidine	2.1	Tyrosine	1.4
Isoleucine	3.8	Valine	4.3
Leucine	5.9		
			73.2

[a] Source: Duchâteau *et al.*, 1953.

VIII. Shellfish Meals

Crab and shrimp meal are increasingly used as animal feed, for as the corresponding industries grow, the amount of waste mounts. An efficient utilization of offal, shells, etc., is gradually becoming urgently needed from both the sanitary and economic points of view.

The biological value of crab meal (protein content 35%) is high (85.9). What is retained in the body is well utilized, but the digestibility (70.7) as well as the net utilization (60.2) is lower than corresponding figures for other marine organisms (Sure and Easterling, 1952). Crab meal is also a most satisfactory ingredient of chick or broiler rations (Parkhurst *et al.*, 1942). Du Toit and Smuts (1941) placed crayfish meal (91) between that of whitefish (94) and herring (73), but Bronkhorst (1938) found crayfish meal better than fish meal. Good results with crayfish meal were also reported by van der Vyver (1951). Crayfish waste from processing plants in the west part of the Cape province constitutes a fine supplement in the feeding of hogs (Johnston and Bartel, 1932).

Both crab and shrimp meal are good when added to soybean meal (Anonymous, 1953) or equivalent to meal scrap in growth effect on hogs (Anonymous, 1952). In the analysis of shellfish meals, erroneously high values for protein are reported, unless a correction is made for the apparent protein contributed by chitin, an N-acetylated glucosamine polysaccharide (Brown, 1959).

The ordinary blue mussel (*Mytilus edulis*) has emerged as a particularly valuable feeding-stuff in the Soviet Union. Preserved with sodium bisulfite or dried, it stays well preserved. It promotes egg production and hog growth efficiently (Kudryavtsev, 1951). Harvesting of mussels for exclusive use in the raising of pigs is even contemplated (Zambriborsč, 1956).

The hunt for unknown accessory growth factors (see Chapter 2, Part I, this volume) is also extended to the field of shellfish meal. Indirect evidence points to their presence in this kind of meal when tested in poultry rations (Sullivan *et al.*, 1960).

As part of a plan to make a constructive approach to the serious problem of the giant African snail (*Achatina fulica* Bowdich) in the Pacific islands, assays of the essential amino acids were made to determine the possibility of using "snail meal" as a source of animal protein in the feeds of poultry and livestock.

The value for arginine is nearly 2⅓ and for lysine more than 1⅓ times the value in whole egg. All other values, although appreciable and significant, fall below the values for whole egg. The deficiencies of oil cake meals could, nevertheless, be readily overcome through the addition of such snail meal (Mead and Kemmerer, 1953).

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CHAPTER 3

Nutritive Aspects of Fish Oils

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I. Nutritive Value of Fish Oil Components

Owing to the complex nature of fish oils, it appears less advisable to make general statements about their nutritive values. Consideration should always be given to their various constituents, their chemical composition as well as their general and specific properties. In spite of massive research in the field of fish oil chemistry (see Chapters 7 and 8 of Volume I), present information is still very scant as to the nutritive implications and certainly too fragmentary to allow even tentative generalizations. The nutritional significance in general of fish lipids was analyzed by Lovern in 1958.

It is common knowledge that fish oils contain glycerides and unsaponifiable matter. The latter varies markedly as to amount, depending on the species of fish. This unsaponifiable matter includes various components, but vitamins such as A, D, or E will not be directly considered here. Fish oils as a source of calories, as well as related aspects, will be mainly discussed in this chapter.

A. Fish Oil Glycerides

As a whole, fish glycerides have the same biological value as fats of land animals and vegetable oils. Compared with terrestrial animal fats, aquatic animal oils show a marked complexity in their fatty acid composition. As a rule, aquatic animal oils involve the whole range of saturated fatty acids from C_{14} to C_{22} and unsaturated acids with from one to six double bonds, whereas land animal fats comprise only a few saturated and monounsaturated members as their chief fatty acid components. These differences, however, usually have a minor influence on their nutritive values as a concentrated source of calories.

Much work has been done in paired-feeding tests with rats originally raised on nonfat diets and later fed a supplement of fish oils as compared to butter and other animal or vegetable fats. Kaneda *et al.* (1955b) confirmed that saury oil displays no difference in the nutritive value from the tea seed oil which consists mainly of triolein. In the experiments of Thomasson (1955), carried out with pair-fed rats on diets containing 10–73 cal. % of herring oil and whale oil, it was found that these aquatic animal oils are equivalent to butter when on a normal rat level. With an increased proportion of aquatic animal oils in the diet, the gain in weight was, however, inferior to that of butter. Kaneda *et al.* (1952a) administered to rats diets containing 15% liver oils of various kinds of shark, and confirmed that liver oils containing less unsaponifiable matter from such fish as ground shark (*Carcarhinus japonica*) and angel shark (*Squatina japonica*) gave growth results quite as satisfactory as when soybean oil was given. Similar findings were reported by Pradhan and Magar (1956) in rat experiments administering 5–20% of shark liver oil. They found that the diets containing 5% oil gave the best results and were in all respects equivalent to those obtained when using hydrogenated vegetable oils. Kaneda (1952) found that the body oil of black cod carries a low iodine number and resembles vegetable oils as to its fatty acid composition. Its nutritive value even exceeds that of olive or soybean oil. Similar findings were also reported by Kaneda *et al.* (1955b) using the oil from the flatfish *Reinhardtius matsuurae* Jordan and Snyder, with an iodine number of 90.

On the basis of these results, it seems reasonable to conclude that fish oils have a good nutritive value if they are administered to animals properly. It is known, however, that the dietary fat frequently is deposited in animal tissues more or less unchanged. Many studies show that exogenous fat may have a marked influence on the composition of the depot fat. Hogs given diets containing 14% of menhaden oil deposit C_{20} and C_{22} fatty acids originating from this oil, though in minor quantities (Brown, 1931). Similar results were obtained when administering whale oil (Garton *et al.*, 1952). The higher poly-unsaturated acids of cod liver oil given to growing chicks appear, however, to be converted into dienoic acids (Reiser, 1950). Fish meal rendered a softer fat in pork and a higher content of poly-unsaturated fatty acids (Dahl, 1957).

Next comes the essential question of digestibility. A coefficient of 98.3 in this respect was found when rats were fed on diets containing 5% of sardine oil (Lassen *et al.*, 1949). A high degree of digestibility (98.2 ± 0.4%) was also encountered after 12 hr. when cod liver oil was given to rats (Steenbock *et al.*, 1936). The corresponding figure for halibut liver oil was 85.4 ± 0.9% after 8 hr. Deuel and Holmes (1922) gave 47 g. of cod liver oil to four men per day and found that the mean value of digestibility was 97.7%. Thomasson (1956) investigated the rate of fat absorption in rats. Butter was absorbed most readily, followed by such vegetable oils as cottonseed oil and olive oil. Next came sesame oil, lard, and whale oil, all being on the same level, followed by sheanut butter and herring oil, while rape seed, poppy seed and kapok seed oils were poorly absorbed.

Numerous studies have been carried out on the effect of cod liver oil in the feeding of rats, chiefly due to the fact that this oil once was the sole source of vitamin A, and the effects of constituents other than vitamin A were too obvious to be ignored. Suzuki *et al.* (1920) observed that cod liver oil developed toxic reactions in the rats when fed quantities exceeding a 2% level. The toxic effects did not disappear after hydrogenation of the oil. Takahashi (1922) and Kawakami (1935) maintained that this toxicity could be attributed to the presence of highly unsaturated acids with several double bonds. Ozaki (1927) established through detailed and lengthy studies that oleic acid had the highest nutritive value, while fatty acids with shorter molecules, such as lauric, myristic, capric, and caprylic acids, came second. In third place were linoleic acid and stearic acid, while linolenic acids showed least value from the nutritive point of view. He also reported that rats could not survive on diets containing a 5% level of clupanodonic acid. Yoshida (1937) found that the highly unsaturated acids isolated from a shark, *Heptranchias perlo*, were toxic, but that this effect could be overcome by the simultaneous administration of massive doses of riboflavin. Blaxter and Brown (1953) noted that severe muscular dystrophy developed in calves given cod liver oil. They concluded that the toxicity of cod liver oil was due to its poly-unsaturated acids and not to a possible overdosage of vitamin A or D. Tange and Takahashi (1944) discovered that the toxic effect of cod liver oil could be prevented by adding 5% of beer yeast to the diet. Schwarz (1948) found that if young rats are given cod liver oil in their diet they develop within a few weeks a fatal metabolic disturbance characterized by acute degeneration of the liver and dystrophy of the skeletal musculature. The disturbance can be completely prevented by the inclusion of vitamin E in the diet. Similar results were also obtained by Tobin (1950) with mice. The effect of the administration of cod liver oil on the deficiency of vitamin E has recently been studied by several investigators (Hove and Seibold, 1955; Jensen *et al.*, 1956; Bunnell *et al.*, 1956; Matsuo, 1957).

It is a moot question to what extent hypervitaminosis A might occur as a result of excessive intake of fish liver oils. The vitamin A concentration of cod liver oil is not so high that the toxicity of this oil can be attributed to the amount of that vitamin contained in the oil. So if the oil should exhibit toxicity, it may be safely concluded that vitamin A is not responsible for it.

B. Highly Unsaturated Acids

As previously described, many workers reported that body fats, liver oils, and component polyenoic fatty acids of fish were toxic. These findings would constitute a paramount problem for those who take fish as their daily food, particularly for the Japanese, whose main animal protein source is fish. Sardine, mackerel, and saury, all rich in fat, can well be said to be staple foods in Japan. The fat content of these fishes changes considerably with seasons. When carrying much fat, they are delicious and are consumed in great quantities. Against this background it is noteworthy that fish poisonings due to fish oils or their highly unsaturated acids have never been reported in Japan. Nevertheless, toxic effects had been observed experimentally. Kaneda and Ishii (1953, 1954) had previously suspected that former investigators might have drawn erroneous conclusions from such animal studies. Unintentionally, they might have influenced the composition of their samples. Fish oils, and particularly highly unsaturated acids, are much more readily oxidized as compared to the fats of terrestrial animals. Even if fish oil samples used for experiments were extracted and purified from fresh material almost in the state in which they are present in the tissues of living fish, they still might be oxidized to some extent in the meantime while the animal experiments are being conducted. It is quite difficult to keep them unchanged during the whole period of animal experiments.

Bromination has frequently been applied to procure polyenoic fatty acids from fish oils, but the samples regenerated from the polybromides are considerably contaminated with isomers and other products. Such samples obviously should not be employed in establishing the nutritive value or the toxicity of polyenoic acids. Kaneda and co-workers isolated polyenoic acids from mixed fatty acids of sardine oil by the sodium salt-acetone method, fractional distillation of ethyl esters under reduced pressure, and chromatography. These samples were used in animal experiments with the utmost precaution for preventing any denaturation. The results thus obtained were quite different from earlier findings. They were able to demonstrate that the polyenoic acids caused no toxic reactions whatever in rats. An excellent growth of the animals was obtained, and the coefficient of digestibility was 94.3, which is slightly lower than that for oleic acid used as a control for comparison. On account of the finding that any toxic effects of body and liver oils of fish could be avoided by massive doses of vitamins, the vitamin levels in these experiments were kept at minimum levels. These investigations have established convincingly that highly unsaturated acids as such are not toxic, in contrast to previous findings.

As to the nature of an eventual toxic principle in fish oils, Kaneda *et al.* have made the assumption that this might be identified as the initial oxidized products of the polyenoic acids. Consequently, they prepared oxidized products of polyenoic acids by exposing to air oil samples prepared by the methods described above. Rats fed such oils all died within one week after ingesting the diets containing these oxidized oils at a level of 5%. They also noted that similar results were obtained when feeding oxidized products of less unsaturated acids.

Kaneda and Ishii (1954) and Kaneda *et al.* (1954a, b) undertook experiments to isolate the most toxic fraction from such autoxidized polyenoic acids. They found that this toxic principle was concentrated in that fraction which did not form urea complexes. Supplemental tests pointed to the possibility that the toxicity was attached to compounds with a peroxide structure. Therefore, autoxidized products of highly unsaturated acids were dissolved in a mixture of chloroform and acetic acid and treated with potassium iodide to destroy the peroxides. This procedure is identical to that employed in determining the peroxide value of fatty materials. Samples treated in this way did not exert any toxic effects. Similar results were obtained when administering peroxidized products of less unsaturated acids, from which the peroxides had been removed in the same way. The 50% lethal dose of peroxidized unsaturated acids to mice was established as follows: $LD_{50} = 300$ mg. total peroxide oxygen per kilogram. Moreover, Kaneda *et al.* (1954d, 1955a, b) administered autoxidized unsaturated acids to rats and investigated the organ tissues just before the premature death of these rats. The tubules were unusually expanded at the boundary of the medullary and cortical parts of the kidney, and a cell infiltration had taken place in the intestinal mucous membrane. They also inferred that autoxidized fish oil products may exert certain effects on the mitochondria of the liver. This was later verified by Ottolenghi *et al.* (1955), who observed that methyl linoleate and methyl linolenate, irradiated by ultraviolet light, exerted an adverse effect on succinoxidase, choline oxidase, and aminoxidase, all belonging to the mitochondria in rat livers. Furthermore, Matsuo (1957) found that oxidation products of polyenoic acids react with protein and precipitate this latter, resulting in a more or less complete inactivation of the enzyme systems in test animals.

A new clue to the toxic effect of these peroxides may be obtained through the findings of Andrews *et al.* (1960) with air-oxidized soybean oil. This inhibits the intestinal xanthine oxidase—an effect which may be reversed by exogenous flavin-adenine-dinucleotide (FAD). Consequently, the specific toxicity of the lipid peroxides may be at the level of the intestinal enzymes.

What has been said with regard to fish oils is largely applicable to the related fats and unsaturated acids of squids. Ogata *et al.* (1955) gave rats a sample of oxidized, highly unsaturated acids obtained from cuttlefish oil. Histological examinations revealed lesions in the heart, acini of the liver, spleen, kidney and other organs. Necrotic areas were observed in the mucous membrane of the stomach, colon and ileum. Matsuo (1954, 1957) confirmed the toxicity of oxidized polyenoic acids from squid oils. Also in this case the toxic potency of autoxidized polyenoic acids ran parallel to the amount of peroxides.

Groot and Obbink (1953a, b) studied the nutritive characteristics of rancid cod liver oil. According to them, normal growth is obtained in the rats fed on diets containing 10% of rancid cod liver oil with a peroxide value below 24. If the value exceeds 54, the growth of the rats is not satisfactory. When the oil is heated at 230°C. *in vacuo* for 3 hr. to reduce the peroxide value, normal growth is obtained. On heating to 230°C., fresh liver oil gives rise to toxic compounds, too, but these are different from those formed in rancid oil. This toxic matter is partly counteracted by large quantities of α-tocopherol acetate.

According to Irving (1956), a whitening of the upper incisor teeth and histological changes in the enamel structure occur when the rats were fed on vitamin E-free diets containing cod liver oil, but these changes were averted by adding α-tocopherol. When hake liver oil was substituted for cod liver oil, the effects became extreme and could not be prevented through α-tocopherol.

The relationship between vitamin E and fish oils is discussed in Chapter 9 on the use of fishery products in feeding. Muscular dystrophy, white muscle disease, and other drastic symptoms may be experimentally induced through vitamin E deficiency. Knowledge that cod liver oil can be toxic when given in excess to various animals dates back to observations by Agduhr (1926) and has since then been repeatedly confirmed. Cod liver oil actually intensifies the severity of certain lesions associated with avitaminosis E. Such symptoms may in turn be due to excessive use of fish oils or to quite normal administration of fish oils without taking into consideration the increased requirements of vitamin E when the fat concentration is elevated. In spite of the action of cod liver oil as an antagonist to vitamin E, therefore, the presence in the oil of substantial amounts of this vitamin, nevertheless, seems indisputable (Brown, 1953; Moore *et al.*, 1959)—this in contrast to earlier notions that it was devoid of this vitamin.

From the observations of Dam (1944), we know that highly unsaturated fatty acids can oppose the action of vitamin E. It thus seems safe to conclude that in cod liver oil these substances are the main antagonists to vitamin E.

There are some studies on the changes in the nutritive value of processed aquatic products which might be attributed to the rancidification of the oils contained in them. Honcamp (1933) examined the nutritive value of herring meals, one of which contained much oil and other less. He reported that he was able to raise hogs as effectively on the former meals as on the latter. This only proves that the protein was fully utilizable and no detrimental factor existed in the oil. Kaneda *et al.* (1955b), however, extracted oil from sardine meals with methanol and benzene and found that the nutritive value of this oil was much inferior to that of soybean oil and it appeared to have practically no food value. This latter result indicates that although the oxidation of the oil in fish meals has proceeded past the peroxide stage and no longer exhibits any marked toxic effect, it may, nevertheless, have lost much of its nutritive value. Biely *et al.* (1955) reported that the oil in herring meals retards the growth of poultry. Kaneda *et al.* (1954c) have extracted oils from dried saury, mackerel, and herring, which are all consumed extensively by the Japanese, and examined their nutritive value. As the saury oil has a high iodine value, the oil deteriorates considerably during the manufacture and storage of the dried fish. This is, however, roasted before being served, and thus the peroxides disappear markedly. These research workers also noticed that the application of an antioxidant in the manufacture of dried fish effectively reduces the deterioration of the oil. According to Shimooka and Toyama (1958), peroxides in the oil of dried fish decrease during the storage at room temperature without heating, and the oil becomes similar to that contained in fish meals. Takahashi and Masuda (1938) reported that the nutritive value of oil extracted from smoked herring was high.

Finally, to what degree the poly-unsaturated acids of fish oils are active as essential fatty acids (EFA) factors is not sufficiently studied in regard to individual acids. The earlier concept that the chemical structure of the major poly-unsaturated acids contains the double bond arrangement of the divinyl ethane type has been found to be erroneous by recent investigations. These works show that the double bond arrangement of poly-unsaturated acids of fish oils is of the divinyl methane type as in linoleic, linolenic, and arachidonic acids. Also it is generally accepted that individual poly-unsaturated acids of fish oils are chiefly of the linolenic type, the acids of the linoleic type being very small in amount. Only the acids of the linoleic type exhibit all the EFA activities. Consistent with these findings, the EFA content corroborated by the bioassay value is reported to be very small for cod liver, menhaden, and herring oils (Thomasson, 1953), for concentrates of poly-unsaturated acids from tuna oil (Privett *et al.*, 1959), for tuna, herring, and menhaden oils (Privett *et al.*, 1960), and for menhaden body oil (Ahrens *et al.*, 1959; Stoffel and Ahrens, 1960).

Several fish oils exhibit the same depressive effect on serum cholesterol levels as do linoleic and linolenic acids. This has been demonstrated for sardine oil by Anderson *et al.* (1957), for cod liver oil by Hauge and Nicolaysen (1959), for tuna and menhaden oils by Peifer *et al.* (1960), and for lingcod, halibut, and shark liver oils by Wood and Biely (1960a, b). Whole cod liver oil was as effective as linolenic acid, but the poly-unsaturated acids of the cod liver oil caused a greater drop than the entire oil (Hauge and Nicolaysen, 1959). According to Nicolaysen and Ragard (1961), cholesterol-depressive effect of marine oils corresponds fairly well to their content of poly-unsaturated acids. The effect of cartilaginous fish oils is less pronounced in this respect (Wood and Biely, 1960b). According to Robe (1958), arachidonic acid, common in several fishes such as sardine and herring, also markedly lowers blood cholesterol. The heart tissue accumulates these poly-unsaturated acids. Thus fish oils resemble the more unsaturated type of vegetable oils in tending to lower blood cholesterol levels. Additional findings to this effect with human subjects have been reported by Bronte-Stewart *et al.* (1956), by Keys *et al.* (1957), and by Ahrens *et al.* (1959). Similar influences have been reported for whale oil (Malmros and Wigand, 1957) and seal oil (Bronte-Stewart *et al.*, 1956), which have a fatty acid composition similar to that of fish fats. The practical significance of such findings naturally depends on the amount of fat-rich fish habitually consumed by any individual, in relation to the rest of his dietary fat intake.

The unsaponifiable portion of cod liver oil does not contain a cholesterol-depressant factor according to findings by de Groot and Reed (1959) in experiments with rats.

Herring oil is subject to controversial findings, showing, according to Wood and Biely (1960b), an increasing effect on blood cholesterol, in man, in comparison with traditional fats. March *et al.* (1959), on the other hand, found that herring oil differs from butter, lard, chicken fat, and shortening as a dietary supplement, not raising the cholesterol values in the blood of experimental chickens, even when they were fed a low protein diet.

C. MISCELLANEOUS

It has been known for many years that oils of aquatic origin, such as those of fish and whale, contain a substantial amount of unsaponifiable matter besides the glycerides. Although no systematic studies have been made on the nutritive value of these compounds, certain findings of nutritional importance will be reviewed here.

1. *Higher Alcohols*

The oil of sperm whale contains considerable amounts of alcohols, such as cetyl, octadecyl, and oleyl alcohols, the chemical structures of which correspond to those of corresponding higher fatty acids. One particular fish, *Ruvettus preticosus* Cocco, also contains these alcohols in large amounts. These aliphatic alcohols seem to be widely distributed in many other marine animal oils in minor quantities. It is also well known that α-glyceryl ethers, such as batyl, chimyl, selachyl alcohols and others, are present in certain oils of marine animals, particularly in the liver oils of certain sharks (elasmobranchs) where they occur in appreciable amounts (see further Chapter 7, Volume I).

Nutritive evaluations of these alcohols are chiefly available for the oil of sperm whales, as they are most abundant and readily obtained. Sahashi (1933) administered them together with glycerides and observed that sperm whale oil caused fatal seborrhea in rats. Somekawa (1933, 1938, 1941a, b, 1942a, b, 1947, 1949) concluded that the cause of this seborrhea could be ascribed to these esters of higher aliphatic alcohols, in each of which one ethylenic bond was present. Thus oleyl alcohol, oleyl palmitate, and cetyl palmitate were not responsible for seborrhea, but oleyl oleate was active in this respect. Hydrogenated sperm oil did not cause seborrhea, but rats fed this oil on a 15% level did not survive. Kaneda and Sakurai (1954) established, however, that rats fed diets containing 15% oleyl alcohol developed no definite seborrhea symptoms, but certain toxic reactions were apparent. Seborrhea was obtained when oleyl oleate was administered in accordance with Somekawa's previous findings; but, contrary to his observations, cetyl oleate, oleyl stearate, and octadecyl oleate all caused seborrhea also. It was thus concluded that esters of higher aliphatic alcohols and fatty acids are potent agents in causing seborrhea, regardless of double bonds. It is not yet known if this is true in cases when the molecular weights of fatty acids are small or the melting points of the esters are high. The fact that oleyl alcohol is toxic, although it does not cause seborrhea, was recently confirmed by Matsuo (1957).

Oleyl alcohol is readily absorbed by rats and deposited in the liver tissues (Channon and Collinson, 1928). When sperm oil is administered to rats, the wax fraction of oil is partially digested (Fujii *et al.*, 1954a, b; Fujii and Okura, 1954, 1956a, b, 1957a, b; Fujii *et al.*, 1956). Lipids isolated from internal body organs and muscles of rats which were fed oleyl oleate to induce seborrhea had low saponification values and contained a great deal of unsaponifiable matter (Kaneda and Sakurai, 1954). Oleyl alcohol and cetyl alcohol were isolated from the hair oil of rats that had ingested oleyl oleate. This points to the possibility that oleyl oleate is not sufficiently utilized in the body of rats when administered in large amounts and consequently accumulates in the tissues, inducing seborrhea. When sperm oil or oleyl oleate is administered, hydrocarbons are accumulated in quantities 150 times and sterols 5 times greater than in normal rats (Kaneda *et al.*, 1957). These same authors also noted that seborrhea could be largely prevented by the adding of kephalin, isolated from soybean oil, to the ingested fat.

Ethyl esters of mixed fatty acids, derived from sperm head oil, are not toxic and are well utilized as a calorie source (Akiya *et al.*, 1950). Glycerides isolated from sperm oil constitute good food; nevertheless, their nutritive value was enhanced by the addition of ethyl linoleate in small quantities (Fujii and Okura, 1957a, b). Mancke (1927) administered cetyl acetate to sheep and goats and found that the amount of unsaponifiable matter was not increased in their milk fats. He considered it likely that cetyl alcohol was oxidized to palmitic acid. Trial feeding of geese showed that the digestibility coefficient was 62. No cetyl group was detected in their depot fats. Thomas and Flaschenträger (1923) indicated that dogs absorb cetyl alcohol rather poorly, but its esters are more readily utilized. Cetyl alcohol was absorbed less than oleyl alcohol by rats, but better than cholesterol. The uptake of these compounds ran parallel to their solubilities in bile salts solution (Channon *et al.*, 1928). De Stetten *et al.* (1940) confirmed that cetyl alcohol was absorbed in rats and discovered that it was rapidly converted into palmitic acid in the intestinal mucosa. They also demonstrated the conversion of deuteropalmitic acid to deuterocetyl alcohol in the intestinal wall. Blomstrand and Rumpf (1954) indicated that 1-C^{14}-cetyl alcohol was to some extent oxidized into palmitic acid in the intestinal mucosa of rats and this acid in turn incorporated into the lymphatic triglycerides.

Information is scant as to the nutritive value of dihydric-ether alcohols such as chimyl, batyl, and selachyl alcohols, frequently found in some shark liver oils and other marine animal oils. Kaneda and Ishii (1952a) fed rats on diets containing 15% of such liver oil in which approximately 30% consisted of these alcohols. In the rats fed for 35 days, the gain in weight was about 90% of that obtained with soybean oil, and the digestibility coefficient was around 93. Nevertheless, as soon as batyl or selachyl alcohol in a pure state was given to rats, the intake was poor, even when its amount was less than that contained in the liver oils (Kaneda *et al.*, 1955b). The idea that this might be ascribed to the high melting point of batyl alcohol was refuted, because the corresponding acetate with a low melting point was also poorly ingested by the rats. These findings indicate that these alcohols are accepted by the rats only when they are combined with fatty acids rendering esters. The real cause for this is, however, difficult to conceive.

Rats fed for 2 months on diets containing 2% levels of batyl and selachyl alcohols deposit abnormal quantities of unsaponifiable matter in the tissues of the intestinal organs and muscles (Kaneda *et al.*, 1955b). When stearyl alcohol was fed to rats at a 1.8% level in the diet, a digestibility coefficient of 88.6 was obtained; when it made up 7.5% of the diets, the digestibility coefficient dropped to 54.8 (Calbert *et al.*, 1951). Sperry and Bergmann (1937) reported that an appreciable increase occurs in liver sterols when ostreasterol obtained from oysters and from other mollusks is administered to mice.

2. *Hydrocarbons*

It is well known that the highly unsaturated hydrocarbon squalene $C_{30}H_{50}$ is present in certain shark liver oils. Also, a saturated isoparaffine, pristane $C_{18}H_{38}$, and an unsaturated hydrocarbon, zamene $C_{18}H_{36}$, accompany squalene in minute quantities. An unsaturated hydrocarbon, gadusene, constitutes a minor constituent of cod liver oil. These hydrocarbons seem to be widely distributed in fish oils (Toyama and Tsuchiya, 1935). Of all these compounds, none has aroused so much biological interest as squalene.

Channon (1926) demonstrated that squalene is absorbed by rats and deposited in the liver and body fats as a part of the unsaponifiable fraction. He noticed, too, that the storage of squalene in the tissues is only temporary, since it starts to disappear as soon as the feeding of this compound terminates. Yamasaki (1950) studied the fat of squalene in rabbits. To some extent, squalene is excreted by the kidney and digestive tracts. The squalene appearing in the liver remains stored for approximately 3 months. Rats fed on 3% of squalene develop seborrhea symptoms and die (Sakurai and Masuhara, 1952). Diets containing 5% of squalene cause the same disease in the rat as sperm oil or oleyl oleate does, and premature death follows (Kaneda *et al.*, 1955b). The ensuing composition of the body fat of rats, fed on squalene, is summarized in Table I. The hydrocarbon levels are two to ten times above normal in

TABLE I
Effect of Squalene-Containing Diet on the Body Fat of Rats

	Portion	Fat (fatty acids + unsaponifiable matter) (%)	Fatty acids (%)	Unsaponifiable matter		Hydrocarbon			Sterol	
				%	% in fat	%	% in fat	% in unsaponifiable matter	%	% in unsaponifiable matter
Fat-free basal diet	Hair	9.70	1.85	7.85	80.92	4.393	45.29	55.97	1.95	24.79
	Skin	1.54	0.88	0.66	42.85	0.096	6.25	1.46	0.09	13.89
	Muscle	4.35	3.16	1.19	27.35	0.057	1.32	4.85	0.14	12.07
	Liver	2.87	2.17	0.70	24.39	0.061	2.15	8.82	0.17	24.41
	Intestine	3.95	2.21	1.74	44.05	0.085	2.16	4.91	—	—
Supplemented with 0.5 g. squalene per day for 14 days	Hair	18.54	1.48	17.06	92.01	11.208	60.45	65.70	2.15	12.62
	Skin	3.94	0.29	3.65	92.63	0.681	17.29	18.67	0.25	6.78
	Muscle	0.92	0.29	0.63	68.47	0.193	20.99	30.66	0.07	11.50
	Liver	1.70	1.04	0.66	38.82	0.061	3.57	9.21	0.14	21.66
	Intestine	3.92	0.72	3.20	81.63	1.538	39.25	48.09	—	—

such tissues as hair, skin, muscle, and intestine when squalene is ingested. Squalene at a level of 0.5 g. per day showed a digestibility coefficient of 72.2 in rats. In spite of the toxic effect of squalene, in small quantities it may exert a lactation-promoting effect (Ridi *et al.*, 1955). The rats on squalene-free diets showed normal growth and reproduction, but the lactation was unsatisfactory. The lactation index was elevated from 34.9 to 92.1 and the lactation period prolonged when 0.1 g. of squalene was added to the diet. High and Day (1951) administered β-carotene and squalene to a vitamin-A-deficient rat and found that large amounts of squalene reduced the amount of vitamin A stored in liver and kidney.

As early as 1926, Heilbron *et al.* (1926), Channon (1926), and Channon and Tristram (1937) postulated the biosynthesis of cholesterol from squalene. Langdon and Bloch (1952, 1953a, b) administered squalene to rats, together with isotopic acetate. Radioactive squalene was subsequently isolated from the liver. They demonstrated that squalene is converted to cholesterol *in vivo*. Tomkins *et al.* (1952, 1953), however, failed to show that the synthetic squalene (Dauben and Bradlow, 1952) was a direct precursor to cholesterol and attributed this to the fact that they are different isomers. They studied the fate of radioactive squalene both *in vivo* and *in vitro*. Squalene was not incorporated into cholesterol under varying experimental conditions.

II. Edible Oils from Fish Sources

As discussed previously, fish oils as such are not toxic. Their nutritive value is maintained if well preserved. As a rule, however, they are rich in ethylenic bonds and readily attacked by oxygen, thus becoming rancid and developing unpleasant odors and flavors. These deteriorated fish oils are by no means suitable as foodstuffs.

As indicated above, most fats used for human consumption are unsaturated, and especially those from fish and other marine sources. These fats then often undergo a series of changes that will affect their nutritional value. The changes depend upon the degree of unsaturation and the amount of heat applied. In the presence of air, the changes will consist of peroxidation and partial decomposition, a deteriorative sequence collectively known as autoxidation or oxidative rancidification. If the same fats are heated in the absence or near-absence of air, the process is known as thermal polymerization, which also results in the formation of unwholesome by-products. In principle, there are two major methods for the manufacturing of edible oils or fats from fish oils: hydrogenation, giving solid fats, and polymerization. These two major groups of modified fish oils will be reviewed below. It should, however, be observed that most of the clinical research work concerned with autoxidized and heated fats involves the use of test animals whose stomachs are organized on an anatomical pattern differing basically from that of man. The results, consequently, have limitations in their applicability.

A. Hydrogenated Fish Oils

Numerous studies are available on the nutritive value of hydrogenated fish oils. It has been generally agreed that no particular differences exist between these products and those manufactured in a similar way from vegetable oil. Certain differences may, however, appear but are generally ascribed to the longer carbon chains of the fatty acids in fish oils as compared to those of hydrogenated vegetable fat. The degree of hydrogenation also influences the nutritive value.

Ueno *et al.* (1927, 1928, 1935) found that the nutritive value of fish oils is generally improved by hydrogenation. When hydrogenating sardine oil, a fat having an iodine value of 53.4 was obtained. This was deodorized by steaming and refined further through treatment with fuller's earth. Fed to rats, it showed a high nutritive value and even surpassed olive oil when vitamin A was added.

Higashi *et al.* (1949) concluded that the nutritive value of fish oil was improved through hydrogenation and ascribed this to the better stability of such oil rather than to the removal of the toxic, highly unsaturated acids. These research workers also found that the hydrogenated sardine oil with an iodine value of 90 had a higher nutritive value than the hydrogenated sardine oil with an iodine value of 62 and the former was superior even to butterfat. Hara (1949) examined the relationship between iodine values and digestibility coefficient for a number of hydrogenated oils. The following coefficients, 88.9, 92.8, and 94.3, corresponded to the iodine values 62, 90, and 110, respectively.

The lack of stability and the immediate detrimental rancidification of nonhydrogenated whale oil were underlined by Malmros and Wigand (1957).

Through hydrogenation, solid "iso-oleic" acids can be obtained. They are deposited in the tissues of rats (Barbour, 1933). Kaneda and Ishii (1952b) isolated solid unsaturated acids from hydrogenated sardine oil and administered their ethyl esters to rats in order to determine their nutritive value. They were only slightly inferior to ethyl oleate, employed as a control, and far better than the saturated fatty acids of hydrogenated sardine oil. According to Kaneda *et al.*, the nutritive value of fatty acids with long carbon chains in the hydrogenated sardine oil is not inferior to that of ethyl oleate. These findings indicate that hydrogenation, when controlled, results in products with good nutritional characteristics.

B. Polymerized Fish Oils

Almost all fatty oils are capable of polymerization reactions. The iodine values drop while molecular weights and viscosities increase when they are subjected to high temperatures for some length of time. Some particular aspects of polymerized fish oils will be discussed.

Lassen and co-workers (1949) prepared polymerized sardine oils with iodine values of 160, 140, and 120 through heating the oil to 250° C. in a nitrogen atmosphere. Rat-feeding experiments indicate that in this way the digestibility was reduced and in direct proportion to the iodine value. The coefficient was 94.9 for an oil with the iodine value of 160, and 84.8 for that with an iodine value of 120. Polymerized corn oil is toxic through compounds formed from the unsaturated fatty acids (Johnson *et al.*, 1956). They suggested that these toxic substances may exert some adverse effects on enzyme systems and destroy vitamins. Frahm *et al.* (1953) heated whale oil at 280°C. for 8 hr. At a level of 65 mg. a day, mice showed intestinal disturbances and lost weight, finally resulting in death. They concluded that polymerized oils are not suitable for food. Dangoumau *et al.* (1957, 1958) could not observe any toxicity of polymerized corn oil, as reported by Johnson *et al.* (1956).

Crampton *et al.* (1951a, b, c, 1953, 1956) undertook extensive studies on the nutritive value of polymerized oils. They heated such vegetable oils as linseed and soybean oils at 275° C. in an atmosphere of carbon dioxide. Herring oil was polymerized by heating at 280° C. for 10 hr. under a diminished pressure of 10 mm. Hg and in passing steam. Animal experiments indicated that these heat-polymerized oils had lower nutritive value than the original oils. They also fractionated the polymerized ethyl esters of linseed oil fatty acids by vacuum distillation and the urea-complex methods. They identified certain cyclic monomeric acids as toxic. Common *et al.* (1957) prepared ethyl esters from menhaden oil and heated these at 275° C. for 15 hr. in a carbon dioxide atmosphere. The most toxic principles were encountered in the portion which did not form urea complexes. Matsuo (1957) obtained similar results with heat-polymerized cuttlefish oil. There is further evidence for an association between the toxicity of the non-adduct-forming fraction (NAFD) and the presence of polyene acids in the original oil as shown in studies on menhaden oil (Common *et al.*, 1957). Further, Matsuo (1958, 1959, 1960a, b) concluded from the results of a series of detailed experiments that the most toxic principles are the cyclic monomers produced by intramolecular rearrangement of poly-unsaturated acids.

No evidence of impaired nutrition or harmfulness to the test animals was experimentally observed when rats, both male and female, were fed several highly polymerized oils (Alfin-Slater *et al.*, 1959). A slight depression in growth and a reduced reproductive performance in the female animal occurred, but was readily alleviated by a supplementation with α-tocopherol.

Groot and Obbink (1953a, b, c, d) noted that cod liver oil with a high peroxide value was toxic, but when heated at 230° C. *in vacuo* for 3 hr., the peroxide values dropped and the toxicity disappeared. Rats fed on oil treated this way grew satisfactorily. Nicolaysen and Pihl (1953) carried out feeding experiments with a commercial, heat-treated herring oil. They administered to rats and human beings sardines which were canned in this polymerized oil, and found no differences in appetites, rates of growth, weights of feces, or their total fat content as compared to packs in olive oil. Sasaki *et al.* (1951) carried out experiments on artificial digestion tests with slightly polymerized sardine and flatfish oils employing pancreatin. Slightly polymerized oils showed somewhat better digestibility than the original untreated oil, and when they were polymerized to an excessive degree they became inferior to unheated oil with regard to utilization in the body. When polymerized oil prepared from fin-whale oil was given to rats, it caused toxic reactions at a 20% level, and most animals died. At a 10% level, no toxic effects were noticeable, and the oil seemed to be utilized satisfactorily as a source of calories (Sakurai *et al.*, 1951). Kakinuma *et al.* (1951) gave a similarly polymerized whale oil to human beings and established a digestibility coefficient of 90.2. Similar results were obtained by Hara (1949).

Edible oils are manufactured in Germany by polymerization of marine oils (Werner, 1951). They are used as frying oils and for other cooking purposes. Hugel (1951) reported that the process has been so improved that odorless, bland, and stable polymerized oil has recently been manufactured which has a digestibility coefficient of 94, measured in living bodies.

It is evident that there are two conflicting groups of findings in this field, one asserting that the nutritive value of polymerized oil is low, and the others claiming the reverse. Polymerized oils with low biological values are mostly processed at temperatures exceeding 250° C. and for longer periods of time. As Täufel (1952) points out, it is quite conceivable that such excessive heat processing causes ring formation and other reactions in the oil that render toxic compounds. Higashi and Kaneda (1950) suggested that fish oil would be more stable against oxidation and its nutritive value maintained at a high level, if unstable ethylenic linkages were removed through a slight polymerization, instead of hydrogenation. They polymerized sardine oil and found its nutritive value higher than that of the original oil. Kaneda and Arai (1953) polymerized a mixture of liver oil of a shark (*Heptranchias perlo*) and soybean oil by heating at 150° C., using fuller's earth as a catalyst, and then deodorized the product by steaming. The oil thus prepared was found to have a higher nutritive value than the original liver oil.

A comprehensive discussion on whether autoxidized (heated) oils constitute a nutritional hazard was presented by Newman (1958a, b) but not restricted in its scope to marine oils. He also brings in the question of an oxidative destruction of vitamin A, thus creating the basis for an avitaminosis caused by a lack of vitamin A. Furthermore, an extensive review covering the entire field of changes in heated oils and the nutritive effects of such changes taking place in their composition was recently published by Perkins (1960). This study clearly bears out the lack of reliable evidence in spite of all experimentation. The lack of a distinct terminology in this area is evident. Also, Rao (1960) stated in a recent review article that experimental evidence in this regard is still awaited and hence it is too early to draw any definite conclusions about the causes of toxicity of rancid and heat-treated oils and their components.

That heated fats could exert a detrimental effect on vitamin A and bring about its oxidative destruction was observed as early as 1924 by Fridericia in studies with dehydrogenated whale oil and was later the subject of special investigations by Harrelson *et al.* (1938), Dyne (1939), Dyne *et al.* (1940a, b), which largely confirmed this. Experimental rats showed a hepatic depletion of vitamin A. Whether this is a secondary effect due to gastric disturbances or specifically related to toxic reactions is not established. Differences between the gastrointestinal systems of man and the rat must also be taken into account. According to recent French reports, polymerized fish oils reduce growth in white rats and induce disturbances in the fat metabolism, leading to cellular infiltrations of a myocardic-sclerotic nature (Raulin *et al.*, 1960). Further investigations in this respect are most justified.

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CHAPTER 4

Fat Soluble Vitamins

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I. Introduction

Fish oils are the richest known sources of vitamins A and D. The stores of these vitamins which accumulate in the livers of many fishes are much higher than those found in the livers of most mammals. The great disparity in vitamin A reserves, for example, is apparent when the content of vitamin per gram of liver in some specimens of soupfin shark, 50,000 i.u./g., is compared with that of the sheep, 600, or that of the rabbit, 170 (Moore, 1953a). An even greater disparity exists in respect of vitamin D, which occurs in the liver and in the body fat of mammals only in insignificant amounts, often less than 1 i.u./g. (Bacharach, 1946), whereas in a number of species of fish the liver oils may contain from 20,000 to 45,000 i.u./g. (Table VI).

The ultimate origin of vitamin A in fishes is probably β-carotene, which is present in the diatoms (Strain, 1944) on which small crustacea, such as shrimps, subsist. The latter contain the preformed vitamin (Kon and Thompson, 1949; Fisher *et al.*, 1951) and are consumed by small fishes, which in turn form the food of the larger species. It has been demonstrated that the cod can convert β-carotene to vitamin A (Neilands, 1947), but whether it receives the major part of its vitamin A in the preformed state or as provitamins is uncertain.

The origin of vitamin D in fish has been much discussed. It is improbable that provitamins D in the tissues are converted to vitamins D by the action of ultraviolet light on the body surface, as in mammals. The activating rays of the sun penetrate only to a depth of one meter (Darby and Clarke, 1937), and fish normally inhabit much deeper waters, out of reach of these rays. Moreover, basking sharks, which are exceptional in that they are exposed to sunshine for long periods while lying on the surface of the ocean, accumulate practically no vitamin D.

Potential dietary sources of the vitamin appear to be scanty. Its presence has been demonstrated in the floating brown alga or gulfweed (*Sargassum*) which is produced in vast quantities in the Caribbean Sea, and is later dispersed by the Gulf Stream to areas as far distant as Iceland. The alga harbours a multitude of mollusks, shrimps, and other small invertebrates, and provides a plentiful supply of fish food. Darby and Clarke (1937) reported that the dry matter of the fronds contained about 3% of oil, which was definitely antirachitic when tested on rats. Insignificant amounts of the vitamin are found in zooplankton (Drummond and Gunther, 1930, 1934) and in copepods (Copping, 1934).

Fish probably ingest considerable quantities of provitamins D, since these occur in many marine invertebrates (Deuel, 1957a). There is at present no convincing evidence that fish can convert provitamins into vitamin D, since the energy required for this conversion is unlikely to be derived from ultraviolet light, as mentioned before. If conversion does occur, we have, furthermore, no evidence to decide whether the fish employs provitamins from an external source, or whether it forms its own provitamin by dehydrogenation of cholesterol. The origin of vitamin D in fish, therefore, is at present almost entirely a matter of speculation. The question is discussed by Bills (1954), who first suggested (Bills, 1927) that vitamin D may be synthesized by fish.

There is a profusion of data on the vitamin A and vitamin D contents of fish oils, but the number quoted here is necessarily limited. Extensive compilations to which reference can be made include those of Fixen and Roscoe (1937, 1939), Butler (1946), Bailey (1952), and Bills (1954).

In the following tables ranges of values are listed where these are available; the single figures quoted from Bills (1954) represent average values. In other instances, single figures should not be regarded as typical of a species, since wide variations occur between individuals, according to the age or sexual condition of the fish, or the season at which the samples were collected.

II. Factors Affecting Vitamin Content

A. AGE AND SIZE

One of the main factors affecting the vitamin content of the liver oils is the age, and thus the size and weight, of the fish. In contrast to mammals, fish continue to grow after reaching full maturity, so that in some species old fish may attain considerable size and weight. There is much evidence that with increasing age vitamin A accumulates in the liver, since no great demands are made on the reserves for metabolic purposes, and therefore the potency of the liver oil and the vitamin A content of the liver are greater than in younger and smaller specimens.

Some fish appear to start life with negligible reserves of vitamin A. In the soupfin shark, a viviparous elasmobranch, the liver of the mother may contain a total of 12 million units, but little or none of the maternal reserves are transferred to the foetus (Molteno *et al.*, 1945), a finding observed also in mammals (Moore, 1953b). Age is difficult to assess in the soupfin shark, but after maturity is reached, the potency of the liver oil and the vitamin A content of the liver increase rapidly with increase in length of fish. Ripley and Bolomey (1946), in their studies of the soupfin shark (*Galeorhinus galeus*) of Californian waters, found that in males less than 155 cm. long (the average length at maturity) the potency of the liver oil averaged less than 50,000 i.u./g., but with subsequent increase in length a potency of over 200,000 i.u./g. might be attained. Molteno *et al.* (1945) noted that the livers of soupfin sharks caught in deep waters were consistently richer in vitamin A than those of sharks caught in shallower waters, but they attributed this to the fact that the bigger specimens are seldom found inshore. In the spiny dogfish (*Squalus acanthias*) (Templeman, 1944), and in the dogfish (*Squalus suckleyi*) (Swain, 1947) increase in size greatly increases the vitamin A potency of the liver oil. In the latter species the values, per gram of oil, in female fish weighing 3 lb. and 9½ lb. were 3,700 and 66,400 i.u., respectively. Corresponding values for the total liver reserves of the vitamin were 0.47 and 5.94 million units.

A direct relationship between age of fish and the potency of the liver oil was observed in the cod by MacPherson (1933), and also by Pugsley *et al.* (1945). According to MacPherson, the potency was related to age rather than size, since a slow-growing fish could accumulate a greater amount of vitamin A in the liver than a more rapidly growing one of the same size. The concentration of vitamin A in the liver oil of the halibut increases with increase in size of liver and, therefore, with size of fish (Lovern *et al.*, 1933) but in the groper (*Polyprion oxygeneios*) (Shorland, 1953) and the ling (*Genypterus blacodes*) (Shorland, 1938) the larger livers yield a less potent oil. The total reserves in these two species are not much affected by size of fish, whereas in the halibut (Lovern *et al.,* 1933) considerably greater reserves are found in the larger specimens. In the kingklip (*Genypterus capensis*) the increase in the vitamin A reserves with size is due to an increase in the percentage of liver in the fish and the percentage of oil in the liver, rather than to an enhanced concentration of vitamin A in the oil (Rapson *et al.,* 1944c).

In the eel (*Anguilla aucklandi*) the percentage of oil in the body tissues, and also its potency, increase with age. The increase in oil content appears to be associated with a transference of the vitamin from liver to body tissues, so that the ratio "nonliver vitamin A": liver vitamin A is greater in old than in young fish (Edisbury *et al.,* 1937a).

The gradual accumulation of the vitamin with age and/or size has been noted also in the yellowtail (Rapson *et al.,* 1945d), the maasbanker (Kallir *et al.,* 1944), the long-jaw flounder (*Atheresthes stomias*) (Swain and Barraclough, 1947), in members of the Sparidae (Corbett *et al.,* 1945), and in a number of other species.

Vitamin D storage in relation to age and size has been less extensively studied, but it is probably influenced in the same way as the storage of vitamin A, at any rate in some species, e.g. the stockfish (*Merluccius capensis*), in which both the potency of the liver oil and the total amount of vitamin D in the liver are greater in the older fish (Rapson *et al.,* 1944b). Pugsley does not give data for the amount of vitamin D stored per fish, but he observed that while increase in age increased the potency of the liver oil in the gray cod (*Gadus macrocephalus*) (Pugsley, 1939c) this was not so in the halibut (*Hippoglossus hippoglossus*) (Pugsley, 1939b) and the grayfish (*Squalus suckleyi*) (Pugsley, 1939a).

B. Season and Feeding Habits

In many species of fish the amount of oil in the liver exhibits a marked seasonal fluctuation which is influenced probably by many factors, but mainly by variations in food intake and by metabolic changes in the fish during the reproductive cycle. In general, an approximately inverse relationship exists between the amount of oil in the liver and its vitamin A potency. At periods when the fish is feeding sparingly, the yield of liver oil is low, but the concentration of vitamin A is high; when food intake is increased, fat infiltrates into the liver and the concentration of the vitamin is reduced (Drummond and Hilditch, 1930).

Variations in food intake are related to sexual condition, both in viviparous and oviparous species. The soupfin shark (*Galeorhinus galeus*), according to Ripley and Bolomey (1946), eats little during the development of the foetuses, presumably because the pregnant females find it difficult to secure food. The fish loses condition and the oil reserves of the liver decrease, since they are utilized to compensate for the deficiency in food intake, but these workers consider that they are not drawn upon to any appreciable extent in the later stages of pregnancy for the nourishment of the young embroys, as the large yolk sac contains enough nutrients to maintain the young until the time of birth, and there is, moreover, no placental membrane for transfer of food. Although the liver of gravid sharks is usually very rich in vitamin A, the parental reserves are not depleted to any appreciable extent during reproduction either in the snapper shark (Cunningham and Slater, 1939) or as already mentioned, in the soupfin shark (Molteno *et al.*, 1945).

The extent of the changes which occur in the amount and potency of the liver oil during the sexual cycle of the South African soupfin (*Galeorhinus canis*) are exemplified by the data of Karnovsky *et al.* (1948). A female carrying fully developed foetuses may have only about 26% of oil in the liver, but with a vitamin A content of 200,000 i.u./g. or more, whereas in females carrying unfertilized eggs or young embryos, the liver contains about 70% of oil, though of a much lower potency, of the order of 10,000 i.u./g. In males, according to Ripley and Bolomey (1946), the seasonal variation in the liver oil reserves is much less marked (50–60%) than in females.

In oviparous species, as, for example, the cod, food consumption is high during the prespawning period and the liver contains much oil, about 70%, but when spawning begins, the cod virtually ceases to eat. It draws heavily on its reserves of oil for the provision of energy, and also for the production of ova, which contain considerable quantities of oil. The liver oil is therefore reduced, sometimes to less than half its original amount. Some vitamin A is transferred to the ova, but the amount is insufficient to impair appreciably the total vitamin reserves, so that the potency of the oil increases. After spawning, the food intake returns to normal, and the fat deposits are replenished, with consequent dilution of the vitamin concentration of the oil (Lovern *et al.*, 1933; Lovern, 1934).

Pugsley (1939c) noted that the oil content of the livers of the gray cod (*Gadus macrocephalus*) was higher, and the vitamin A potency lower, during the autumn and winter months than at other seasons. Several species of British Columbian flatfishes exhibit a similar seasonal trend (McKercher, 1946). The maximum range of values was observed in the brill (*Eopsetta jordani*), the percentage of oil varying from 9 to 27, and the vitamin A potency from 6,800 to 132,000 i.u./g. of oil.

The pronounced seasonal fluctuations in the vitamin A concentration of halibut liver oils encountered by Lovern *et al.* (1933), from 8,000 i.u./g. in February to 106,000 i.u./g. in May, were due to causes other than changes in the oil content of the liver during spawning. They suggested that variations in the dietary intake of carotene, correlated with the abundance or scarcity of diatoms, were responsible, though diatoms are only the first link in the food chain of the halibut. As an alternative explanation they mentioned that the fluctuation in potency might be associated with a transference of vitamin A between the liver and some other part of the body, which was influenced by some factor which varied seasonally in the same way as the supply of diatoms. That the organs to which the vitamin is transferred, if such transference takes place, are probably the intestines and pyloric caeca, is indicated by observations in the geelbek (*Atractoscion aequidens*), in which, during intensive feeding, the vitamin A content of these tissues is increased apparently at the expense of the liver reserves (Molteno and Rapson, 1939). At the same time there is an increase in the oil content of the intestines and pyloric caeca, and the authors suggest that these findings are in accord with the hypothesis that in fishes vitamin A is concerned in the assimilation of fat (Edisbury *et al.*, 1938; Lovern and Morton, 1939; Lovern *et al.*, 1939b).

In contrast to most other species, the New Zealand ling (*Genypterus blacodes*) exhibits relatively slight changes in the potency of the liver oil throughout the season (Shorland, 1935, 1937).

The vitamin D potency of liver oils varies seasonally as does the vitamin A potency, but within a much narrower range. Its inverse relationship to the oil content of the liver was demonstrated in the cod by Hess and his associates (1929), and in the halibut by Bills *et al.* (1934a). The latter workers noted that the yield of oil from pooled halibut livers was lowest (12%) in January, at which time the vitamin D content was at a maximum of 1,400 i.u./g. In August, the oil yield increased to 25%, and the concentration of the vitamin was at a minimum, 900 i.u./g. Pugsley *et al.* (1945) found that the livers of well-nourished, nonspawning cod were rich in oil of relatively low potency; during spawning an increase in potency occurred as the oil content of the liver was reduced. In specimens from the Gaspé peninsula, the vitamin D values, which varied from 22 to 152 i.u./g. of oil, were lowest in the autumn. When the yield of vitamin D from fish within a given age group was expressed as units per 100 g. of fish, the seasonal change in potency was not apparent. A range of 700–1,300 i.u./g. oil during the season has been recorded in the stone bass (*Polyprion americanus*) by Rapson and Schwartz (1944) and a rather wider range, 500–6,000 i.u./g., in the snoek (*Thyrsites atun*) (Rapson *et al.*, 1944a), but in the kingklip (*Genypterus capensis*), in which the changes in the oil content of the liver are small, there is no significant seasonal variation in the vitamin D potency of the oil (Rapson *et al.*, 1944c). The yield of pilchard oil, prepared from the entire fish, increases from July to October, and concomitantly there is a decrease in its vitamin D concentration from 100 to 50 i.u./g. (Pugsley, 1942).

III. Vitamin A

The forms of vitamin A which contribute to the biological potency of fish oils include vitamin A_1 and the more highly unsaturated form, vitamin A_2. Besides the all-*trans* isomers of these vitamins, various *cis* isomers also occur, but a discussion of these is beyond the scope of this chapter. It may be mentioned, however, that the name neovitamin A has been given to a *cis* isomer of vitamin A_1, present in fish liver oils, which is less readily crystallizable than the all-*trans* form. In marine fish vitamin A_1 preponderates, though a small amount of vitamin A_2, less than 5% in most species, is also present (Morton and Bro-Rasmussen, 1955). In many fresh-water fish, on the other hand, vitamin A_2 is the predominant form (Lederer *et al.*, 1937; Edisbury *et al.*, 1937b; Gillam *et al.*, 1938). In euryhaline fish, i.e., those which are able to live either in the sea or in fresh water, an intermediate position exists. Thus the liver oil of the salmon (*Salmo salar*) resembles that of fresh-water fish in containing a substantial amount of vitamin A_2, while the oil from the pyloric caeca, in which vitamin A_1 is the main form, is more akin to the marine fish oils (Edisbury *et al.*, 1938).

A. Liver

The importance of the liver as a site of fat storage and vitamin A deposition varies greatly in different species. In some species it is the main reserve of both fat and vitamin A, while in others the nonhepatic viscera or the skeletal musculature may contain as much or more vitamin A than the liver. There is evidence that the vitamin is not distributed uniformly throughout the liver tissue. In the slender-toothed shark (*Carcharias taurus*) and the soupfin shark (*Galeorhinus canis*) the potency of the liver oil diminishes from the upper hepatic portion to the tip of the lobe (Molteno *et al.*, 1945). A similar distribution occurs also in the dogfish (*Squalus suckleyi*) (Yamamura and Kondo, 1949) but in certain teleosts, the lingcod (*Ophiodon elongatus*) and the halibut (*Hippoglossus hippoglossus*), the tip of the lobe contains the most potent oil (Brocklesby and Rogers, 1941).

1. *In Elasmobranchs*

Elasmobranchs, i.e., fishes which have a so-called cartilaginous skeleton, generally accumulate fat and vitamin A mainly in the liver and

TABLE I
THE VITAMIN A CONTENT OF LIVER OILS OF ELASMOBRANCHS

Common name	Systematic name	Oil in liver (%)	Vitamin A (i.u./g. oil)	References
Brown shark	*Apristurus brunnius*	73–80	nil	Sanford and Bonham (1950)
Basking shark	*Cetoerhinus maximus*	70–76	trace	Molteno *et al.* (1945)
Spotted eagle ray	*Stoasodon narinari*		35	Springer and French (1944)
Spotted whip ray	*Batoidei* sp.		145	Angulo *et al.* (1948)
Skate	*Raja nasuta*	47	290	Shorland (1950)
Frilled shark	*Chlamydoselachus anguineus*	72	600	McRary (1948)
Cow-nosed ray	*Rhinoptera bonasus*		675	Springer and French (1944)
Slender-toothed shark	*Carcharias taurus*	53–75	1,800[a]	Molteno *et al.* (1945)
Nurse shark	*Ginglymostoma cirratum*		2,000–3,700	Angulo *et al.* (1948)
Wahlbeehm's sharp-nosed shark	*Carcharinus walbeehmi*	26–52	1,600–6,400[a]	Molteno *et al.* (1945)
Mud shark	*Hexanchus griseus*	40–70	1,000–7,000	Swain (1944)
Man-eater or great white shark	*Carcharodon carcharias*		750–7,400	Springer and French (1944)
Seven-gilled shark	*Heptranchias pectorosus*		3,500–7,500[a]	Molteno *et al.* (1945)
Tiger shark	*Galeocerdo arcticus*		4,000–9,000[a]	Molteno *et al.* (1945)
Sand-bar shark	*Carcharinus milberti*		2,600–15,500	Springer and French (1944)
Common Cape dogfish	*Squalus acutipinnis*	31–61	5,000–16,000[a]	Molteno *et al.* (1945)
Thresher shark	*Alopias vulpinus*	37–39	1,000–17,500	Sinnhuber and Law (1947)
Great blue shark	*Prionace glauca*	37	17,700	Sinnhuber and Law (1947)
Little black tip	*Isogomphodon limbatus*		4,000–22,000	Springer and French (1944)
Sawfish	*Pristis pectinatus*		5,000–26,000	Majumdar (1941)
Blue shark	*Carcharinus glaucus*	30–50	9,000–26,000[a]	Molteno *et al.* (1945)
Sharp-finned whaler	*Carcharinus brachyurus*	63	54,000	Shorland (1950)

TABLE I (*continued*)

Common name	Systematic name	Oil in liver (%)	Vitamin A (i.u./g. oil)	References
Dusky shark	*Carcharinus obscurus*		6,500–58,500	Springer and French (1944)
Hammerhead shark	*Sphyrna zygaena*		3,300–60,600	Angulo *et al.* (1948)
Pacific dogfish	*Squalus suckleyi*	30–80	1,500–65,000	Bailey (1952)
Southern hammerhead shark	*Sphyrna diplana*		5,400–137,000	Springer and French (1944)
Atlantic dogfish	*Squalus acanthias*		200–150,000	Bailey (1952)
Soupfin shark	*Galeorhinus canis*	28–78	10,000–157,600[a]	Molteno *et al.* (1945)
Soupfin shark	*Galeorhinus zyopterus* ♀	51–70	10,000–68,000	Sinnhuber and Law (1947)
	♂	45–65	48,000–190,000	Sinnhuber and Law (1947)
School shark	*Galeorhinus australis* ♀ + ♂	42–56	2,500–375,000	Shorland (1950)
	♀	69	19,200–615,000	Shorland (1950)

[a] Values for $E^{1\%}_{1\,\mathrm{cm}}$ 328 mμ given by the authors have been multiplied by 1,600.

little in other tissues; the liver of *Squalus suckleyi,* for instance contains about 98% of the total vitamin A of the fish (Higashi *et al.,* 1953).

Much attention has been directed to the investigation of the liver oils of elasmobranchs, as a result of the discovery about 1937 that the liver of the soupfin shark was a rich source of vitamin A and, particularly during World War II, of great commercial value. The vitamin A contents of the liver oils of many species from different areas are, therefore, available, some of which are shown in Table I. These illustrate the extremely wide differences in the vitamin A concentration of the liver oils that exist between species. At the lower end of the scale are the basking shark and the brown shark, with liver oils practically devoid of the vitamin, while at the upper end are the soupfin sharks, with oils which may contain more than half a million units per gram. Moreover, between individuals of the same species, the variations may be almost as great as between species, owing to the influence of such factors as age and season, which have already been discussed. The yield of oil from individual specimens of the soupfin shark varies enormously, since not only does the concentration of vitamin A in the liver oil range from 2,500 to over 600,000 i.u./g., but, according to Shorland (1950), the oil content of the liver may be as low as 23% or as high as 87%, while the percentage of liver in the fish varies from 2.75 to over 20%. Although the highest potencies are found in the liver oils of females in the later stages of pregnancy, males usually have considerably more potent oils than females. (See Table I.) Ripley and Bolomey (1946) observed that the amount of vitamin A per unit weight of liver was also greater, about 2–3 times as much as in females of comparable length, carrying no eggs, unfertilized eggs, or young embryos. The presence or absence of ripe sperm did not appear to influence the vitamin A content of the oil or of the liver.

The soupfin shark ranks as an outstandingly valuable source of vitamin A, irrespective of its habitat, but the South African specimens examined by Molteno and his colleagues appear to have oils less potent than those of the New Zealand (Shorland) and Pacific (Sinnhuber and Law) species. Some of the hammerhead sharks, which belong to the genus *Sphyraena,* and some members of the genus *Carcharinus,* rank next to the soupfin sharks in the potency of their oils. Skates and rays as a rule accumulate little of the vitamin, as also do some specimens of the Atlantic dogfish (*Squalus acanthias*), the potency of the liver oil in the latter being in some instances as low as 200 i.u./g. The variation between individual dogfishes, however, is extreme, as values up to 150,000 i.u./g. have been recorded, but Bailey (1952) states that the average potency is usually low, about 1,500 i.u./g.

2. *In Teleosts*

In the teleosts, or bony fishes, fat may be localized mainly in the liver or distributed in other tissues, head, body, or nonhepatic viscera, as well as in liver. The deposition of vitamin A does not necessarily accompany the deposition of fat. In the gadoids, such as the cod, the haddock, and the hake, the liver is the principal site of storage of both fat and vitamin A; in the yellowtail (*Seriola lalandi*) it is the site of storage of vitamin A, but not of fat, which is distributed throughout the tissues, the main deposits being in the head and body, but these contain no vitamin A (Rapson *et al.*, 1945d). Other species, likewise with a diffuse system of fat distribution, accumulate substantial amounts of the vitamin in other tissues as well as in liver, e.g., in the visceral oils, as in the halibut (Edisbury *et al.*, 1938) or in the body tissues, as in the fresh-water eel (Edisbury *et al.*, 1937a).

a. Marine Teleosts

Reference to Table II shows the extreme variation in the concentration of vitamin A in the liver oils which exists between species in marine teleosts, the maximum value in the red steenbras being 10,000 times that in the haddock. The gadoids have the least potent oils (though that of the gray cod of the Pacific may attain high values), but since the yield is large and easily obtained, cod liver oil is commercially one of the most important vitamin-containing oils. Its vitamin A potency may vary considerably—from 400 to 4,000 i.u./g. (Fixen and Roscoe, 1937). The specifications adopted by different countries for cod and other marine oils are listed by Bailey (1952).

The salmon and the sardine, which store considerable amounts of oil in the muscle tissue, yield liver oils low in amount but of relatively high potency. It would appear that certain feeding grounds or environmental conditions are more conducive to the accumulation of vitamin A than others, since the hake of New Zealand (*Merluccius gayi*) and the hake of South Africa (*Merluccius capensis*) have liver oils many times richer than those of the species (*M. vulgaris*) of the North Sea. Nevertheless, some species are evidently less affected than others by these factors, as the liver oils of the Pacific halibut (*Hippoglossus stenolepis*) are comparable in potency to those of the North Sea halibut.

The Heterosomata, to which the flatfishes belong, have livers less rich in oil than the gadoids, but in some species, such as the petrale sole and the halibut, the concentration of vitamin A in the oils is high. Very large amounts of the vitamin are also found in the tunas, and especially in the sea basses and swordfish, members of the order Percomorphi.

The red steenbras, a fish which attains a large size, provides an example of the remarkable concentrations of vitamin A which may occur in liver oils. In one specimen examined by Rapson and his co-workers the oil contained well over one million units per gram, that is to say,

TABLE II

THE VITAMIN A CONTENT OF LIVER OILS OF MARINE TELEOSTS

Common name	Oil in liver (%)	Vitamin A (i.u./g. oil)	References
Haddock	50–75	100	Lovern *et al.* (1933)
Codling (smaller specimens)		100	Lovern *et al.* (1933)
Codling (larger specimens)		300	Lovern *et al.* (1933)
Cod (mean of 43 samples)	50–75	1,000	Lovern *et al.* (1933)
Whiting	50–75	200	Lovern *et al.* (1933)
Dab		500	Lovern *et al.* (1933)
Ling	Ca. 70	500	Lovern *et al.* (1933)
Pollock (Atlantic)		1,000	Lovern *et al.* (1933)
Hake (Atlantic)	50–75	1,000	Lovern *et al.* (1933)
Lemon sole	Ca. 15	2,000	Lovern *et al.* (1933)
Pollock		2,000	Bills (1954)
Squirrel hake		2,000	Bills (1954)
Plaice (Northeast Atlantic)		3,000	Lovern *et al.* (1933)
Turbot (North Atlantic)		10,000	Lovern *et al.* (1933)
Salmon (Atlantic)		10,000	Lovern *et al.* (1933)
Albacore (Pacific)		12,000	Bills (1954)
Sardine (Pacific)		16,000	Bills (1954)
Ling (Oceania)	33–38	2,000–16,000	Shorland (1950)
Hake (Oceania)	Ca. 35	18,000	Shorland (1950)
Hake (S. Africa)		1,000–25,000[a]	Black *et al.* (1946)
Gray cod	15–45	1,500–30,000	Bailey (1952)
White steenbras	2	30,000[a]	Rapson *et al.* (1945d)
Striped tuna		36,000	Bills (1954)
California mackerel		45,000	Bills (1954)
California bonito		57,000	Bills (1954)
Bluefin tuna		65,000	Bills (1954)
Atlantic tuna		80,000	Bills (1954)
Groper	11–13	40,000–90,000	Shorland (1950)
Geelbek		53,000–142,000[a]	Black *et al.* (1946)
Japanese tuna		170,000	Bills (1954)
Petrale sole	6–25	4,000–175,000	Butler (1946)
Yellowtail (Atlantic)	0.7–11	61,000–236,000[a]	Rapson *et al.* (1945d)
Kabeljou		48,000–275,000[a]	Black *et al.* (1946)
Maasbanker	9–10	293,000[a]	Rapson *et al.* (1945d)
Halibut	15–20	6,000–330,000	Lovern *et al.* (1933)
Swordfish	8–35	20,000–400,000	Butler (1946)
White sea-bass	15–25	40,000–400,000	Butler (1946)
Black sea-bass	13–20	500,000	Bills (1954)
Red steenbras	1–9	29,400–1,130,000[a]	Rapson *et al.* (1945d)

[a] Values for $E^{1\%}_{1\,\mathrm{cm}}$ 328 mμ given by the authors have been multiplied by 1,600.

30–40% of the oil consisted of vitamin A. If, as is probable, the vitamin was largely in ester form, there can, as the authors point out, have been only a very small percentage of glycerides in the oil, which was, in fact, a natural vitamin A concentrate. The concentration in the liver itself, judging from the data given, was of the order of 70,000 i.u./g., a value surpassing that of polar bear liver, 20,000 i.u./g. (Rohdahl and Moore, 1943), which when eaten by man, causes symptoms characteristic of hypervitaminosis A. Rapson and his associates indeed learned that some fishermen who had eaten the liver of a red steenbras experienced such toxic effects.

b. FRESH-WATER TELEOSTS

Fresh-water fishes, as previously mentioned, differ from marine species in having a greater proportion of vitamin A_2 than of vitamin A_1 in their tissues. The entire body of the brown trout (*Salmo fario*), for example, contains 0.5 mg. vitamin A_2 and 0.25 mg. vitamin A_1 (Edisbury *et al.*, 1938). In many of the liver oils of fish from Russian rivers the ratio of vitamin A_2 to vitamin A_1 is also 2:1 (Lederer *et al.*, 1937; Gillam *et al.*, 1938), while in the liver oils of Indian species it is reported to be still higher, about 9:1 (Balasundaram *et al.*, 1955).

TABLE III
THE VITAMIN A CONTENT OF LIVER OILS OF FRESH-WATER TELEOSTS

Common name	Vitamin A (i.u./g. oil)	References
Pike	3,000	Lovern *et al.* (1933)
Burbot	4,000	Holmes *et al.* (1941)
Carp	5,000–7,000	Raffy *et al.* (1945)
Perch	10,000	Holmes *et al.* (1941)
Pike	14,400	Holmes *et al.* (1941)
Eel	5,700–16,500	Edisbury *et al.* (1937)
Sturgeon	26,000	Lovern *et al.* (1933)
Columbia River smelt	32,600	Sinnhuber and Law (1947)
Columbia River chub	36,000	Sinnhuber and Law (1947)
Whitefish	59,500	Schmidt (1948)

The data given in Table III show that the liver oils of different species of fresh-water fish vary greatly in their concentrations of vitamin A, but in some instances the potencies are high, particularly in the whitefish of the Saskatchewan lakes, a species which feeds mainly on crustacea and mollusks, rather than on plankton (Wynne-Edwards, 1952). The liver oil of this fish is comparable in potency to that of the California bonito.

The distribution of vitamin A in the liver oils of fresh-water species has been studied more extensively by Indian than by other workers, since in India fresh-water fish are abundant and provide a valuable source of the vitamin, although the yield of oil is low, usually between 3 and 8% (Ahmad *et al.*, 1945). Seshan (1940) records values ranging from 2,000 i.u./g. oil in *Catla catla* to 45,000 i.u./g. in *Mystus macronus*, while in species from the Punjab rivers most of the liver oils contained from 20,000 to 26,000 i.u./g. (Ahmad *et al.*, 1945). The vitamin A contents of a number of Indian river fish oils are also given by Datta and Banerjee (1933), Basu and De (1938), and Basu *et al.* (1939).

B. VISCERA (EXCLUDING LIVER)

The nonhepatic viscera of some species, though containing only small amounts of fat, may contain substantial amounts of vitamin A. In the halibut, in particular, the viscera yield very potent oils, containing up to 8% (260,000 i.u./g.) of the vitamin (Lovern *et al.*, 1937). Only traces are found in the stomach; over 90% of the "visceral" vitamin is localized in the intestines and pyloric caeca, chiefly in the tunica propria layer of the mucosa. The oil from these tissues contains about 30% of the vitamin, almost entirely in ester form, while the total amount present is comparable to that in the liver (Edisbury *et al.*, 1938; Lovern and Morton, 1939; Lovern *et al.*, 1939a; Glover and Morton, 1948). The visceral oils of the cod (*Gadus callarias*) and the salmon (*Salmo salar*) are many times more potent than the liver oils, and in the latter the pyloric caeca, which are large, contain more vitamin A than the liver (Edisbury *et al.*, 1938). In the hake, also, the intestines usually contain more than the liver, both in concentration and total amount, though there is no consistent relation between the amount of vitamin in the two sites (Grangaud *et al.*, 1949).

The observation that the alimentary tract of certain fishes contains large amounts of vitamin A led the British workers to postulate that the vitamin may assist in the absorption of food, and especially of fat. This so far is the only role, apart from the formation of visual pigments, which has been suggested for vitamin A in the metabolism of fish.

Table IV gives examples of the vitamin A content of the visceral as compared with the liver oils in a number of species. The Pacific cod and halibut resemble the corresponding North Sea species examined by Edisbury and his colleagues (1938) in having visceral oils considerably more potent than those of the liver, a finding which applies also to the Columbia River smelt, but in a number of instances the concentration of vitamin A is greater in the liver oils. The Columbia River smelt, or eulachon, is notable for having tissues so rich in oil that when a rush wick is inserted in the dried fish, it burns with a steady flame. Its popular name of candlefish is derived from the fact that it was used as a candle by the Chinook Indians (Hart and McHugh, 1944).

TABLE IV
VITAMIN A CONTENT OF OILS FROM LIVER AND VISCERA OF DIFFERENT SPECIES

Common name	Organ	Oil in organ (%)	Vitamin A (i.u./g. oil)	References
Elasmobranchs				
Soupfin shark (South Africa)	Liver	29.0	74,000	Molteno *et al.* (1945)
	Intestine	0.7	15,500	
Dogfish	Liver	40–70	2,000–20,000	Bailey (1952)
	Viscera[a]	2–4	3,000–6,500	
Marine teleosts				
Pacific cod	Liver	25–45	5,000–17,000	Butler (1946)
	Viscera[a]	1–3	36,000–112,000	
Dover slime sole	Liver	7–19	5,000–31,000	Sinnhuber and Law (1947)
	Viscera[b]	0.5–1.5	1,000–3,000	
Chinook salmon	Liver	8–10	25,000–40,000	Sinnhuber and Law (1947)
	Viscera[b]	6.5	21,000	
Pacific halibut	Liver	11–27	17,000–193,000	Sinnhuber and Law (1947)
	Viscera[b]	4	361,500	
Horse mackerel	Liver	6–15	69,000–512,000	Kallir *et al.* (1944)
	Intestines and pyloric caeca	2–15	17,000–106,000	
Red steenbras	Liver	4	1,064,000	Rapson *et al.* (1945d)
	Intestines and pyloric caeca	1.4	1,113,600	
Fresh-water teleosts				
Columbia river chub	Liver	14	36,000	Sinnhuber and Law (1947)
	Viscera	40	3,800	
Columbia river smelt	Liver	12	32,600	Sinnhuber and Law (1947)
	Viscera	5	81,000	
Whitefish	Liver	7	59,500	Schmidt (1948)
	Pyloric caeca	3	3,600	
	Stomach and intestines	3	700	

[a] Excluding stomach, kidney, and gonads.
[b] Stomach, caeca, and intestines.

Visceral organs other than the intestines and pyloric caeca also yield oils having considerable concentrations of vitamin A. The spleen oil of the halibut contains about 30,000 i.u./g. (Edisbury *et al.*, 1938), while oils from the pancreas and kidney of the deep sea shark (*Heteroscymnus longus*) contain, respectively, 20,000 and 500–26,500 i.u./g. (Higashi *et al.*, 1955). Similar values have also been recorded for these organs in surface sharks (Higashi *et al.*, 1953).

C. FLESH

1. *Fresh*

Fish flesh is, in general, a very poor source of vitamin A (see Table V). The muscle tissues of "lean" fish, such as the haddock, contain little or none; mackerel and herring, which have oily tissues, contain rather more. Salmon flesh varies to some extent in its content, Atlantic salmon being devoid of the vitamin, while Pacific salmon, which belongs to a different genus (*Oncorhynchus*), may have up to 600 i.u./100 g. According to Hirao *et al.* (1954), vitamin A is not distributed uniformly throughout the flesh in the salmon, the concentration being greater in the deep, than in the surface, layers. The flesh of the fresh-water eel is much richer than that of the other species, and the content increases with the size of fish. The value given is for medium-sized specimens. The concentration of vitamin A in eel flesh is low, however, when compared with that of the deep sea shark (*Heteroscymnus longus*), which is stated to contain 9,000–26,000 i.u./100 g. (Higashi *et al.*, 1955).

TABLE V

THE VITAMIN A CONTENT OF FISH FLESH

Type	Vitamin A (i.u./100 g. flesh)	References
Fresh		
Haddock	5	Munsell (1940)
Carp	170	Mar (1941)
Mackerel	180	Booher and Marsh (1941)
Flounder	400	Grangaud (1950)
Herring	40–240	Bacharach *et al.* (1942)
Fresh-water eel	4,500	Edisbury *et al.* (1937)
Atlantic salmon	nil	Pyke and Wright (1941)
Pacific salmon	0–600	Bailey (1952)
Canned		
Pacific mackerel	<30	Neilands *et al.* (1947)
Pacific sardines	<30	Neilands *et al.* (1947)
Tuna	<30	Neilands *et al.* (1947)
Herring	40–200	Bacharach *et al.* (1942)
Brisling (sprats)	100–1,000	Lovern (1946)
Chum salmon	30	Munsell (1943)
Pink	100	Munsell (1943)
Red	300	Munsell (1943)
Chinook	750	Munsell (1943)

2. *Processed*

Since fresh flesh contains little vitamin A, it is to be expected that the processed products will also provide insignificant amounts, and this is evident from the data for canned fish given in Table V. Vitamin A appears to be stable to canning (Lopez-Matas and Fellers, 1948). Lunde (1937) found that the smoking process caused no loss when the fish (herring and sild) were smoked whole, and that there was only a slight loss if the herrings were first filleted. Bailey (1943), on the other hand, reported that smoking completely destroyed the vitamin in both herring and lingcod fillets, although not in black cod, which contained about 1,600 i.u./100 g.

IV. Vitamin D

A. LIVER

1. *In Elasmobranchs*

In contrast to the teleosts, the elasmobranchs store negligible amounts of vitamin D, less than 25 i.u./g. of liver oil in most species (Bills, 1935; Cunningham and Scott, 1944; Bailey, 1952). This fact might suggest that in the absence of a completely calcified skeleton, the metabolic requirements for vitamin D are very low, but the extremely large reserves of certain teleosts appear to be in excess of the amount required merely for calcification, and in these instances the vitamin presumably plays some role other than that associated with the deposition of bone salts.

The paucity of vitamin D in elasmobranch fishes is in strong contrast to the abundance of vitamin A which a number of them, such as the soupfin and some hammerhead sharks, possess, and serves to illustrate that the occurrence of the one vitamin bears no relationship to the occurrence of the other, although in certain teleosts the reserves of both vitamins are high.

2. *In Teleosts (Marine and Fresh-water)*

Vitamin D, like vitamin A, is present in fish oils in more than one form, a fact which was first recognized by Bills and his associates (1934b). This observation was confirmed by molecular distillation technique (Hickman, 1937; Hickman and Gray, 1938), and as many as six different vitamins D were distinguished, though some of these were present only in small amounts. About 70% of the vitamin D of cod liver oil occurred as esters. Alternative forms of the vitamin may have unequal antirachitic activity in different animals; vitamin D_2, for example, is much less effective in the chick, unit for unit, than vitamin D_3, while the two forms are equally effective in the rat. Bills *et al.* (1937) demonstrated that, of

TABLE VI

THE VITAMIN D CONTENT OF LIVER OILS OF MARINE AND FRESH-WATER TELEOSTS

Common name	Oil in liver (%)	Vitamin D (i.u./g. oil)	References
Marine			
Pollock		70	Bills (1954)
Squirrel hake		120	Bills (1954)
Kingklip	26–45	85–130	Rapson *et al.* (1944c)
Atlantic salmon		180	Bills (1954)
Herring, Pacific	3–5	250	Bailey (1952)
Cod	50–75	60–300	Fixen and Roscoe (1937)
Jacopever	14–43	60–300	Rapson *et al.* (1945c)
Greenland halibut		400	Holmes *et al.* (1941)
Gray cod	25–45	85–500	Butler (1946)
Ling (Oceania)	38	500	Shorland (1950)
Petrale sole		500	Bills (1954)
Whiting (Northwest Atlantic)		1,000	Holmes *et al.* (1941)
Starry flounder	4–20	1,000	Bailey (1952)
Stone bass	9–24	700–1,300	Rapson and Schwartz (1944)
Gurnard (South Africa)	4–14	400–2,000	Rapson *et al.* (1945b)
Pilchard (Pacific)		2,300	Bills (1954)
Halibut	8–30	1,000–5,000	Bailey (1952)
Snoek (South Africa)	4–19	500–6,000	Rapson *et al.* (1944a)
Lingcod	8–20	1,000–6,000	Bailey (1952)
Kabeljou	5–27	2,000–6,000	Rapson *et al.* (1945a)
Pacific mackerel		6,300	Bills (1954)
Black sea-bass		9,000	Bills (1954)
White sea-bass		11,000	Bills (1954)
Albacore		13,000	Bills (1954)
Kingfish (Australian)	8	15,500	Shorland (1950)
Atlantic tuna		16,000	Bills (1954)
Groper	13	2,000–19,000	Shorland (1950)
Swordfish		2,000–25,000	Holmes *et al.* (1941)
California bonito		35,000	Bills (1954)
Striped tuna		42,000	Bills (1954)
Bluefin tuna		42,000	Bills (1954)
Oriental tuna		45,000	Bills (1954)
Fresh-water			
Lake sturgeon		<1	Bills (1954)
Mirrgal		9	Basu and Sen Gupta (1940)
Rohu		50	Basu and Sen Gupta (1940)
Ling (Canada)		400	Holmes *et al.* (1941)
Muskellunge		500	Holmes *et al.* (1941)
Sheepshead		750	Holmes *et al.* (1941)
Carp		10,000	Raffy *et al.* (1945)

25 different liver oils studied, some, e.g., halibut liver oil, had the same antirachitic efficacy as cod liver oil, per rat unit, when assayed on chicks; some were definitely less effective, and some more effective, than cod liver oil. The oils relatively the least effective included those of the albacore, the California bluefin tuna, and the oriental and striped tunas. That of the white sea bass was definitely more effective than cod liver oil.

The vitamin D of halibut liver oil has been isolated and identified as vitamin D_3 (Brockmann, 1937) and this presumably is the predominating form in cod liver oil, since the two oils have the same efficacy ratio when tested on rats and chicks. Tuna liver oil contains about 10% of vitamin D_2, as well as vitamin D_3 (Brockmann and Busse, 1938).

The concentration of vitamin D in the liver oils of marine teleosts varies greatly from species to species, from 70 i.u./g. in the pollock to 45,000 i.u./g. in the oriental tuna (Table VI). The distribution of the vitamin is related to some extent to their zoological classification (Bills *et al.*, 1935). The elasmobranchs, which have an imperfectly calcified skeleton, contain very little vitamin D; larger amounts are found in the order Heterosomata or flatfishes; while the highest amounts of all occur in the order Percomorphi, to which the tunas, sea basses, and swordfish belong. These Percomorphs have liver oils very rich also in vitamin A (see Table II). The vitamin D values of their oils given by Bills (1954), which represent average figures, range from 9,000 i.u./g. in the black sea bass to 45,000 i.u./g. in the oriental tuna, but still higher figures have been recorded in exceptional cases, e.g., 250,000 i.u./g. in a specimen of albacore (Bailey, 1952). The liver oils of halibut, and particularly of cod, which are the most commonly used for medicinal purposes, are by comparison low in vitamin D, average values being about 3,000 and 100 i.u./g., respectively (Lovern, 1958).

Few data are available for the vitamin D content of the liver oils of fresh-water fishes, but Table VI indicates that, except in the carp, the potency is low, especially in the mirrgal and rohu of India, which contain negligible amounts. It is of interest that the sturgeon, although not belonging to the elasmobranchs, is devoid of vitamin D.

B. VISCERA (EXCLUDING LIVER)

Vitamin D, in contrast to vitamin A, is not deposited in the visceral oils in preference to the liver oils in any of the species for which data appear to be available (Table VII). No extended study of its distribution, such as has been made of the distribution of vitamin A in the halibut (see Section III, B) has, however, been carried out, which is readily understandable, since the time-consuming technique required at present for its estimation makes such a study almost impracticable.

TABLE VII
THE VITAMIN D CONTENT OF OILS FROM LIVER AND NON-HEPATIC VISCERA OF DIFFERENT SPECIES

Common name	Organ	Vitamin D (i.u./g.)	References
Shad (American)	Liver	50–100	Bailey (1952)
	Viscera[a]	20	
Stockfish	Liver	50–380	Butler (1946)
	Viscera	3	
Gray cod	Liver	85–500	Bailey (1952)
	Viscera[a]	10–35	
King salmon	Liver	100–500	Bailey (1952)
	Viscera[a]	100–200	
Sablefish	Liver	600–1,000	Bailey (1952)
	Viscera[a]	100–200	
Halibut (Pacific)	Liver	1,000–5,000	Bailey (1952)
	Viscera[a]	100–500	
Snoek (South Africa)	Liver	500–6,000	Butler (1946)
	Viscera	85	
Lingcod	Liver	1,000–6,000	Bailey (1952)
	Viscera[a]	100–200	
Sheepshead	Mesentery oil	11	Bills (1935)

[a] Stomach, gonads, and kidney not included.

TABLE VIII
THE VITAMIN D CONTENT OF FISH FLESH

Type	Vitamin D (i.u./100 g. flesh)	References
Fresh		
Cod	nil	Grangaud (1950)
Flounder	40	Grangaud (1950)
Tunny	100–300	Grangaud (1950)
Mackerel	700	Grangaud (1950)
Sardine	1,500	Grangaud (1950)
Herring	300–1,700	Bacharach *et al.* (1942)
Fresh-water eel	4,700	Cunningham (1935)
Canned		
Pacific sardines	300	Neilands *et al.* (1947)
Tuna	100–300	Neilands *et al.* (1947)
Herring	50–400	Bacharach *et al.* (1942)
Sild	390–1,000	Aschehoug *et al.* (1939)
Chinook salmon	300	Munsell (1940)
Red salmon	800	Munsell (1940)
Pink salmon	600	Munsell (1940)
Chum salmon	200	Munsell (1940)

C. Flesh

1. *Fresh*

The body oils of certain fish contain appreciable amounts of vitamin D. The oils of herring and menhaden are equivalent in potency to cod liver oil (Bills, 1927) while that of the pilchard (entire fish) contains from 35 to 100 i.u./g., the potency varying with the seasonal fluctuations in the yield of oil (Pugsley, 1942). Hence significant, though not large, quantities occur in the flesh of fatty fish, but there is practically none in "white" or nonfatty fish, such as the gadoids, and only small amounts in flatfishes such as the flounder (see Table VIII). The distribution of vitamin D in fish muscle, therefore, resembles that of vitamin A. The flesh of the fresh-water eel is particularly rich, but those of the herring, sardine and mackerel, though containing much less, are more frequently consumed, and provide a useful source of the vitamin.

2. *Processed*

Canned fish are a relatively good source of vitamin D, particularly when, as with small fish like the sild, the entire fish is processed. The data of Bacharach *et al.* (1942) suggested that some loss may occur in the canning of herring, but Aschehoug *et al.* (1939) found that vitamin D was stable to canning and subsequent storage of the material. Canned fish are appreciably richer in vitamin D than any of the commonly eaten unfortified foods; butter, for example, contains, per 100 g., 10–100 i.u. (Fixen and Roscoe, 1937), while one egg yolk provides only 50–80 i.u. (Cruickshank, 1946).

V. Vitamin E

As early as 1928, biological experiments on fertility in rats indicated that cod liver oil contains vitamin E (Simmonds *et al.*, 1928), but only recently, following the elaboration of accurate and specific techniques for its estimation, has it been possible to obtain reliable data for the α-tocopherol content of fish oils. Robeson and Baxter (1943) isolated α-tocopherol from the liver of the Mangona shark, and confirmed its vitamin E activity by biological assay. The oil contained about 0.01%, i.e., 100 μg./g.

The α-tocopherol contents of herring body oil and of the liver oils of a number of species are given in Table IX. These data, which are for single samples, are so far unpublished, and are quoted by the kind permission of Dr. R. J. Ward. It will be seen that in the lemon sole and the catfish the α-tocopherol content of the liver oil is relatively high, the value in the catfish liver oil being of the order of that found in wheat germ oil.

The total tocopherol contents of several single specimens of commercial fish oils which have been examined by Einset *et al.* (1957) ranged from 40 μg./g. in sardine oil to 630 μg./g. in sablefish oil (Table IX). The tocopherol was identified as α-tocopherol, by paper chromatography, in the menhaden, tuna, salmon, and sablefish oils (Olcott, 1958). According to Einset and his colleagues, there appears to be an inverse relationship between the rate of auto-oxidation of fish oils and their content of tocopherols.

TABLE IX
THE TOCOPHEROL CONTENT OF FISH OILS

Fish oil (liver)	α-Tocopherol (μg./g. oil)	References
Angler-fish	85	Ward (1958)
Haddock	88	Ward (1958)
Ling	93	Ward (1958)
Cod (Atlantic)	115	Ward (1958)
Whiting (Europe)	117	Ward (1958)
Hake (Atlantic)	203	Ward (1958)
Skate	219	Ward (1958)
Lemon sole (Northeast Atlantic)	543	Ward (1958)
Catfish (Atlantic)	1,112	Ward (1958)
Herring (Atlantic)[a]	146	Ward (1958)
Fish oil (commercial)	**Total tocopherol (μg./g oil)**	
Sardine (Atlantic)	40	Einset *et al.* (1957)
Menhaden	70	Einset *et al.* (1957)
Herring (Atlantic)	140	Einset *et al.* (1957)
Tuna	160	Einset *et al.* (1957)
Pink salmon	220	Einset *et al.* (1957)
Sablefish	630	Einset *et al.* (1957)

[a] Body oil.

Fish oils are evidently much richer in tocopherols than the fats of land animals, which have been reported to contain from 2 to 42 μg./g. (Deuel, 1957b). Whether the tocopherols in fish are of dietary origin, as they appear to be in mammals (Deuel, 1957b), is not yet known. In this connection, however, it is of interest that the highest concentrations of α-tocopherol are found in the liver oils of the lemon sole and the catfish, species which differ from the others in that their diet consists partly (in the lemon sole) or mainly (in the catfish) of shellfish.

It should be noted that although fish oils are relatively rich in tocopherol, they also contain large amounts of highly unsaturated fatty acids, which act as antagonists to vitamin E. Their actual biological potency, therefore, may be much less than would be expected from the α-tocopherol content as estimated chemically.

VI. Summary

Probably the most striking point which emerges from the literature dealing with the fat-soluble vitamins in fish is the extreme difference in the vitamin reserves of different species. We have no clue as to why these differences exist. It is difficult to understand why some sharks, for instance, store enormous quantities of vitamin A while others store little or none. Variations in diet do not appear to be entirely responsible, since some species, such as the halibut, accumulate large amounts of vitamin A, while others on a diet not appreciably different accumulate much less.

The vitamin A absorbed is effectively retained by the liver and stored there in ester form, frequently in amounts so large that if they were suddenly released into the general circulation they would almost certainly be highly toxic. Vitamin A may perforce have to be ingested in considerable amount along with other dietary constituents such as fat and protein, and the excess above that required for metabolic purposes accumulates in the liver more or less fortuitously. The role of vitamin A in fish metabolism has not yet been elucidated, but the large reserves, amounting to several grams, which occur in many fish, imply that its function is not that of a vitamin as commonly understood. The hypothesis has been advanced that it is concerned in the assimilation of food, particularly of fat, and such a process may involve relatively large absolute quantities of the vitamin.

Nothing is known respecting the part played by vitamin D in the metabolism of fish. The imperfect bone formation of elasmobranchs is associated with low reserves of vitamin D, but in mammals only minute amounts of the vitamin are necessary for calcification of the skeleton. The high concentrations in the liver oils of many species, such as the tunas, suggest that in certain fish considerable amounts of vitamin D are essential for processes other than the deposition of bone salts.

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CHAPTER 5

Fish as a Source of Mineral Nutrition

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I. Introduction

The mineral constituents of fish are studied much less than nitrogenous compounds, lipids, or vitamins. Only a few elements have been subjected to thorough analyses, particularly phosphorus, calcium, iron, and iodine. But even in these cases, the factors which govern their great quantitative variability are not sufficiently known. Besides, the majority of the analyses apply exclusively to fish meat. Our knowledge of the mineral composition of offals and that of the whole fish—to a great extent consumed by certain populations of Asia, Africa, and Latin America—

remains most deficient. Finally, it is deplorable that the physiological utilization of the mineral substances of fish is very little studied.

II. Brief Review of Mineral Composition

A majority of the data presented below applies to the composition of fresh fish. An exception has been made, however, as to the phosphorus and calcium of the whole fish, the corresponding studies being made mostly on preserved fish (dried, salted, smoked, or packed in oil).

Most tables on food composition contain compilations of numerous analyses of the mineral content of various marine and fresh-water fish. In most cases these tables have critically reviewed the analyses on which they are based. These listings will not be commented on here. Mention is merely made that the first noncomprehensive study on the mineral composition of fish was published by Atwater in 1892. Spectrographic analyses on a broad front covering most mineral elements were made by Newell and McCollum (1931) on fish meals. Later papers of a general nature were those by Nilson and Coulson (1939) and Stansby (1953). The most comprehensive investigations were those by the Russian scientist Vinogradov (1935, 1937), later published in the United States as a treatise edited by Odum (Vinogradov and Odum, 1953) (see also Vintilescu *et al.*, 1940; Sulit *et al.*, 1953).

A. SULFUR

Fish meat contains from 100 to 300 mg. of sulfur per 100 g. (average: about 200 mg.), the major part of this constituent being part of the sulfurous amino acids (Beveridge, 1947; Airan *et al.*, 1950). The variations observed are explained by considerable differences in the contents of methionine and cystine between species (Schormüller *et al.*, 1950; Pallardel Peralta, 1951; Master and Mager, 1954).

Williams (1897, 1911) published numerous analyses of the sulfur content of cooked fish flesh. It was calculated as SO_2 and ranged from 0.26% in hake to 0.7% in trout.

B. CHLORINE, SODIUM, AND POTASSIUM

These three elements, the physiological roles of which are closely related, have been subject to numerous analyses in fish flesh. The amount varies as shown in the next tabulation (see also Table I):

Element	Milligrams per 100 g. of flesh	
	Extreme values	Average
Chlorine	60–250	100
Sodium	30–150	60
Potassium	250–500	400

Fresh-water fish are somewhat lower in both sodium and potassium content than are salt-water varieties. The ratio of the sodium content to that of potassium is quite similar in both kinds of fish, being 0.213 for salt-water fish and 0.199 for fresh-water fish—roughly one part by weight of sodium to five parts of potassium (Thurston, 1958; Thurston *et al.*, 1959).

For a given species, the range of variations frequently is almost as large as those indicated above. Thus, van de Velde (1932) found from 60 to 160 mg. of chlorine per gram in the mackerel and from 90 to 210 mg. in the plaice.

Thurston (1958) established in his study of 34 species of fish that the sodium content of individual species of salt-water fish ranged from 34 to 96 mg. per 100 g. of fish and averaged 68 mg. The corresponding values for fresh-water fish ranged from 38 to 84 mg. per 100 g. fish with an average of 56 mg.

Official Belgian figures give 70–155 mg. sodium per 100 g. for the flesh of salt-water fish and 33.7–73.3 mg. for fresh-water fish (van Coillie, 1959). The corresponding figures for potassium were 240–400 mg. per 100 g. for flesh of marine species and 132.8–440.0 mg. for fish in fresh waters (rivers) (see also Table I).

Large differences are reported in sodium values for similar species from various geographic areas (Thurston, 1958). The sodium content of whiting from the Atlantic Ocean, for example, is much higher than that of whiting from the Pacific Ocean (82 mg. per 100 g. of fish compared to 65 mg.). Similar large differences were noted with Lake Superior and Lake Huron lake herring (56 mg. compared to 38 mg.), with lake and river sheepshead (84 mg. compared to 59 mg.), and with salt-and fresh-water mullet (81 mg. compared to 52 mg.).

Albacore tuna and Lake Huron lake herring had the lowest content of sodium, with 34 and 38 mg. per 100 g. of fish, respectively. The low value for halibut (53 mg.) was surprising in view of its high content—1.5%.

Diverse ecologic conditions might partially explain this large range of variation (Vinogradov and Odum, 1953). Nevertheless, McBride and McLeod (1956a, b) found still greater fluctuations in the amounts of sodium and potassium in certain species of fish, all caught along the coasts of British Columbia (Canada). For example, the red spring salmon contained from 31 to 61 mg. of sodium and from 320 to 470 mg. of potassium per 100 g., with the variations clearly related to the size of the animal and to the fishing season. On the other hand, the contents of these same elements in ling cod and halibut apparently were not related to size, and the amount of sodium in herring remained practically stable during half of the year.

TABLE I
SODIUM AND POTASSIUM CONTENT OF SELECTED FISH[a]

Fish	Dry matter (%)	Sodium (mg./100 g.)	Potassium (mg./100 g.)	Earlier analyses[b] (% Na mg./100 g.) 1	2	3	4
Fresh-water							
Eel, raw	44.3–49.4	33.3–47.5	132.8–200.0	—	40	73	50–115
Trout, raw	23.6–25.4	47.0–73.3	345–440	—	70	80	—
Trout, boiled	27.6	41.3	237.5	—	—	—	—
Salt-water							
Brill, raw	17.7	86.0	324.1	—	—	—	—
Brill, boiled	27.9	83.1	230.0	—	—	—	—
Cod, raw	18.1–19.2	67.4–80.5	337.5–385.0	60	60	100	—
Cod, boiled	25.0	50.6	221.9	—	—	—	—
Cod, frozen	20.3	64.0	315.7	—	—	—	—
Crucian carp, frozen	26.2	69.3	308.7	—	—	—	—
Haddock, raw	17.1–20.1	70.0–98.9	239.7–335.0	—	—	125	76–86
Haddock, boiled	24.7	77.3	200.0	—	—	—	—
Haddock, frozen	21.0	97.8	345.0	—	—	—	—
Halibut, raw	23.2	73.8	449.0	56	—	—	49.5–70
Halibut, boiled	27.8	50.6	301.3	—	—	—	—
Mackerel, raw	20.0–23.4	90.4–130.9	350.0–437.5	—	—	—	50.7–78.0
Mackerel, boiled	24.2	105.0	310.0	—	—	—	—
Plaice, raw	10.1–19.1	90.4–125.0	317.5–397.3	—	—	96	116
Plaice, boiled	23.5	60.5–83.8	160.0–262.5	—	—	—	—
Skate, raw	22.5	155.0–167.2	268.0–280.0	—	75	—	—
Skate, boiled	25.5	97.2	215.6	—	—	—	—

TABLE I (*continued*)

Fish	Dry matter (%)	Sodium (mg./100 g.)	Potassium (mg./100 g.)	Earlier analyses[b] (% Na mg./100 g.) 1	2	3	4
Salt-water (*cont.*)							
Sole, raw	18.6–20.5	119.0–141.0	315.0–354.5	—	150	115	133–167
Sole, boiled	21.0–25.6	79.8–82.7	162.5–190.0	—	—	—	—
Turbot, raw	17.7–19.8	71.9–88.7	274.3–354.5	—	80	—	78
Turbot, boiled	24.7	75.0	150.0	—	—	—	—
Whiting, raw	19.7–19.8	96.0–155.0	326.2–415.0	—	61	—	100–122
Whiting, boiled	21.9	57.0	215.6	—	—	—	—

[a] van Coillie (1959).

[b] References for earlier analyses: column 1, Bills *et al.* (1949); 2, Randoin *et al.* (1947); 3, McCance and Widdowson (1946); 4, Bähr and Wille (1931).

In Alaska pink salmon a high sodium content is associated with a low content of ash, while a high potassium level parallels a high protein content (Thurston, 1958).

Commenting upon the variations observed in salmon, McBride and McLeod (1956b) wrote: "It is possible that the variations in sodium content noted in the salmon may be related in some way to the period in their life cycle in which they were caught; for instance, to the nearness of the approach of the fish to the time of their spawning migration. Much further work, of course, remains to be done to establish any such relationship."

The chlorine, sodium, and potassium content in the viscera does not seem to have been determined in a systematic way. It may be mentioned, however, that according to Muriel Ledesma (1956) hake eggs contained 840 mg. chlorine per 100 g.

Sodium and chlorine values are generally higher for selachian fish species, crustaceans, and mollusks as compared to those prevailing in teleosts (Carteni and Aloj, 1934a, b). The reverse applies as regards potassium.

C. Phosphorus, Calcium, and Magnesium

1. *Flesh*

Some of the earliest analyses of fish refer to phosphorus (Atwater, 1892; Williams, 1897, 1911). Some figures have been selected from these lists to indicate ranges (Table II). All figures fall into the same order of magnitude as those for various kinds of meats. Williams singles out herring, halibut, and John Dory as rich sources of phosphorus. John Dory showed figures of no less than 1.33%.

The content of phosphorus, calcium, and magnesium in fish flesh, however, is in fact highly variable, as shown in the next tabulation.

Element	Milligrams per 100 g. meat	
	Range	Average
Phosphorus	100–400	220
Calcium	5–200	30
Magnesium	10–60	30

According to De Clercq (1932), meat from fish belonging to the Pleuronectidae family exceeds 1,000 mg. per 100 g. in phosphorus content. Some authors quote still higher figures for calcium. According to Costa Saenz (1952), the meat of *Ethmidium chilcae* contained on the average 186 mg. of calcium per 100 g. In a study of Chilean fishes in this respect, *Thyrsites atun* turned out to have the highest amount of both calcium and phosphorus (Schmidt-Hebbel, 1950).

A great number of investigations refer to various food fishes, both marine and inland, in India, chiefly from the Bombay and Madras provinces as well as the Deccan. They exhibit appreciable variation between species, for example, from 0.26 to 1.73% P_2O_5, and from 0.10 to 1.54% CaO (Saha and Guha, 1939; Niyogi *et al.*, 1941). Freshwater fish (Bengal) show a corresponding variation but decidedly lower and more normal level (Basu *et al.*, 1942; Airan, 1950). Noteworthy is the much higher calcium content of the flesh of marine fishes as compared to figures published from other parts of the world. Setna *et al.* (1944) state for such fish in the Bombay area 1,136 mg. to 97.5, with the major part of the species exceeding 350 mg. per 100 g. As the phosphorus level remains normal, this means a substantially changed Ca/P ratio (see below).

TABLE II

SELECTED FIGURES ON PHOSPHORUS CONTENT IN FISH

	P_2O_5 in flesh (%)	
Fish	Fresh fish[a]	Cooked fish[b]
Cod	0.60	0.34
Eel	0.68	0.37
Haddock	0.97	0.87
Halibut	0.44	1.04
Herring	0.56	0.82
Mackerel	0.56	0.53
Plaice	—	0.32
Salmon	0.59	0.41
Sole	—	0.25
Trout	0.81	0.69
Turbot	0.48	0.30
Whiting	—	0.37
California salmon (canned sample)	—	0.51
Pork	0.16[a]	
Beef	0.29[a]	
Mutton	0.43[a]	
Eggs	0.34[a]	

[a] From Atwater (1892).

[b] From Williams (1897, 1911).

The variability also seems to be considerable within each species: for example, Van de Velde (1932) found amounts of phosphorus ranging from 330 to 740 mg. per 100 g. in mackerel and 240 to 410 mg. per 100 g. in plaice. These fluctuations were tied to numerous factors, especially the content of calcium in the water, to age, sex, and the sexual maturity of the animal (Vinogradov and Odum, 1953); in herring, the Ca/P ratio

TABLE III
SELECTED SOUTH AMERICAN FISH ANALYSES[a]

Fish	Ash (%)	Ca	P	Na	K	I	Fe	Cu	Cl	Common name	Source
Acanthistium pictus	1.53	131	114	tr	tr	tr	0.6	0.4	160	Cherlo	Arevalo Padilla, 1952
Ethmidium chilcae	1.44	186	103	—	—	tr	3.0	tr	58	Machete	Costa Saenz, 1952
Paralonchurus peruanus	1.19	109	209	—	—	11.9	1.2	tr	85	Colo or suco	Vallejos Plantano, 1952
Stromateus sp.	—	48	102	—	—	—	3.6–4.3	—	—	White pomfret	Sawant and Magar, 1958
Neptomenus crassus											
Hard roe	1.10	tr	1200	265	—	—	4.9	0.06	415	Cojinova	
Soft roe	1.11	tr	880	62	—	—	1.0	0.05	98		Bazan, 1956

[a] The figures for the various constituents refer to milligrams in 100 g. fresh weight; tr: trace.

decreased from 3.6 to 1.3 between November and January (De Clercq, 1933); it was somewhat higher in the female than in the male (De Clercq, 1934). Through analyses on numerous fishes of the Indian Seas, values of 150 to 360 mg. of phosphorus per 100 g. were encountered (Khorana *et al.*, 1943). Figures are also available from other sources: tropical Africa (Busson *et al.*, 1953) and South America (Arevalo Padilla, 1952; Castillo La Rosa Sanchez, 1952; see also Table III).

Tables showing the composition of foods (Rose, 1933) report calcium contents of 22 mg./100 g. in the meat of lean fish (edible parts) and 19 mg./100 g. in fat fish. These are the average figures, the extremes of which vary from 6 to 120 mg./100 g. Mollusks and certain crustaceans contain 85 and 69 mg. of calcium per 100 g. (edible parts), respectively. They are thus good calcium sources, although not as rich as milk (118 mg./100 g.).

Carteni and Aloj (1934a, b) found teleosts to contain more calcium and less phosphorus than shellfish. This is largely true, also, for Indian fishes as compared to mollusks and crustaceans (Chari, 1948).

The calcium/phosphorus ratio varies between 0.05 and 0.6 with an average of 0.2. On the whole, fish is less unbalanced than meat as to phosphorus and calcium. Fish consumed whole are a good dietary source of calcium.

The magnesium content is generally higher in the edible parts of selachians and shellfish than in the teleosts (Carteni and Aloj, 1934a, b).

2. *Viscera*

According to De Clerq (1934) the viscera of whiting contain from 560 to 770 mg. of phosphorus and from 1,010 to 1,530 mg. of calcium per 100 g. of dry substance. Based upon 30% of dry substance, these values correspond to 170 to 320 mg. of phosphorus and 300–460 mg. of calcium per 100 g. of fresh material.

3. *Whole Fish*

The whole fish has a much higher phosphorus and calcium content than the meat alone. With various species in Cameroon currently eaten fresh or prepared, Bergeret and Masseyeff (1957) obtained the results shown in Table IV.

In a similar study in Togo, but limited to calcium, Perissé and Le Berre (1957) obtained comparable results on fish eaten whole, shown in Table V.

The richness in calcium is due to the skeleton and scales, which both contain tri-calcium phosphate (apatite) and calcium carbonate. In small-sized species the importance of the scales seems to be of prime order.

According to Da Costa and Stern (1956), Portuguese sardines preserved in oil contain 580, 490, or 54 mg. of calcium per 100 g. respectively, depending upon whether they are intact, boneless, or without both skin and bone. The corresponding amounts of phosphorus are 624, 545, and 320 mg. per 100 g. Skin and scales should then contain close to nine-tenths of the calcium of the fish and more than half of its phosphorus. Perissé and Le Berre (1957) confirmed the importance of the scales, finding 1,643 mg. of calcium per 100 g. in *Sardinella cameroneensis,* when scales were removed and smoked (at 34.5% water) but correspondingly 3,884 mg. in the same fish smoked but with its scales retained (at 15.5% water).

TABLE IV

CALCIUM, PHOSPHORUS, AND WATER CONTENT IN SEVERAL WHOLE FISH (IN CAMEROON)[a]

Fish	Water (%)	Phosphorus (mg. per 100 g.)	Calcium (mg. per 100 g.)
Various species in the fresh stage	72.4	350	888
Ethmalosa dorsalis, dried	10.4	540	1640
Stockfish, dried	23.4	640	776
Ethmalosa sp. (bilolo), dried	17.1	520	1490
Synodontis sp.	20.6	440	1370

[a] From Bergeret and Masseyeff (1957).

TABLE V

CALCIUM AND WATER CONTENT IN SEVERAL WHOLE FISH (IN TOGO)[a]

Fish	Water (%)	Calcium (mg. per 100 g.)
Sun-dried fish		
Engraulis enchrasicholus	23.3	3244
Sardinella aurita	24.9	3982
Smoked and dried fish		
Brachydeuterus auritus	32.0	3796
Brachydeuterus auritus	31.1	3044
Vomer setapinnis	36.1	3005
Vomer setapinnis	40.1	3443
Smoked fish		
Engraulis enchrasicholus	17.8	2680
Sardinella cameroneensis	15.5	3884
Sardinella aurita	22.5	4247
Brachydeuterus auritus	22.7	4857
Sphyraena guachancho	22.1	2732

[a] From Perissé and Le Berre (1957).

Magnesium does not seem to have been analyzed in whole fish.

D. IRON AND COPPER

1. *Flesh*

Fish flesh contains from 0.4 to 5 mg. of iron per 100 g. (Parks and Rose, 1933; Ranganathan, 1938; Nilson and Coulson, 1939; McCance and Widdowson, 1940; Khorana *et al.*, 1943; Airan, 1950). On an average it comes close to one mg. In general, salt-water fish contain more iron than fresh-water fish, although Indian species of the latter group show high values (Airen, 1950). Cod and haddock seem to constitute exceptions to this general rule (Peterson and Elvehjem, 1928; Parks and Rose, 1933). Dark meat is almost twice as rich in iron as white meat (Parks and Rose, 1933; Namiki, 1934).

Part of the iron enters into the formation of a complex of iron-copper-nucleoproteins, from which it is liberated by pepsic or trypsic digestion or through the activity of acetic acid (Saha and Guha, 1940; Saha, 1941b).

The copper content of the flesh is from 0.04 to 0.6 mg. per 100 g., with an average of 0.25 mg. (Lindow *et al.*, 1929; Parks and Rose, 1933; Nilson and Coulson, 1939; McCance and Widdowson, 1940; Saha, 1941a). In contrast to iron, there is no noticeable difference between sea-water and fresh-water fish (Lindow *et al.*, 1929; Parks and Rose, 1933). Oysters are a particularly rich source (3 mg. per 100 g.). This was also shown by most of the above-mentioned research workers, as well as by Carteni and Aloj (1934a, b). Crustaceans frequently contain 0.4–0.7 mg. per 100 g. or even more. Oysters from the eastern coast of the United States carry larger amounts of copper than those from the California coast (Bodansky, 1920; Severy, 1923). See figures given in Table VII.

2. *Viscera*

According to Medina Blanco *et al.* (1956), the eggs of hake are very rich in iron and copper: the analyzed samples contained from 27.5 to 52.5 mg. of iron per 100 g. (average: 38.2 mg.) and from 0.375 to 1.5 mg. of copper (average 1.1 mg.); one of these samples, however, showed only traces of these elements.

Milt seems to be less rich in iron, containing on an average 1.5 mg. per 100 g. (Schmidt-Nielsen and Schmidt-Nielsen, 1939; Reisler, 1952).

E. IODINE

Of all the mineral constituents of fish, iodine seems to show the largest range in content, varying between 0.01 and 0.2 mg. per 100. The amount of this element may even reach 0.5 mg. (Lunde, 1928; Lunde *et al.*, 1930; De Clercq, 1932; Ripperton, 1934; Westgate, 1935; Nilson and Coulson, 1939). The variation is so great that it is difficult to give an average figure; Lovern (1946), nevertheless, suggested 0.17 mg. The first investigator to determine the iodine content of a large number of fish, from both the seas and fresh waters, was Bourcet (1899). Some fifty fresh marine foods and particular fish were analyzed by Tressler and Wells (1924) and several processed products by Wells (1925).

TABLE VI

AVERAGE IODINE CONTENT OF COMMON SEA FOODS[a]

Sea food	Iodine content (μg. per 100 g. fresh weight, edible)
Marine fish	
Sole	16.3
Sea bass	25.0
Sardines	28.4
Mackerel	37.1
Halibut	52.0
Herring	52.0
Sea perch	74.2
Cod	146.3
Haddock	318.0
Anadromous fish	
Sea trout	32.0
Salmon	34.1
Fresh-water fish	
Carp	1.7
River bass	3.0
Lake trout	3.1
River perch	4.0
Fish oils	
Salmon oil	245.0
Cod liver oil	838.7
All others taken together	305.2
Shellfish	
Crabmeat	30.8
Oyster	57.7
Clam	78.3
Lobster	102.0
Shrimp	130.0

[a] Anonymous (1952).

Marine foods—sea fish and shellfish—are by far the richest source of iodine in the ordinary human diet (Anonymous, 1952; Astwood, 1955). Fresh-water fish contain least (30 μg./kg.); anadromous fish, which spend part of their life at sea and part in fresh water, have eleven times as much (330 μg./kg.), and at the top of the scale come the true marine fish, with an average content nearly thirty times that of fresh-water fish (Jarvis, 1928; Anonymous 1952; Reisler, 1952). Correspondingly, the oil from salmon—an anadromous fish—contains very much less iodine than does liver oil from cod—a wholly marine species (see Table VI).

According to Lunde *et al.* (1930), the fishing locality has a considerable influence; thus, with the exception of haddock, fish caught along the California coasts are less rich in iodine than those of the same species caught on the Norwegian coasts. These differences might depend upon the lower iodine content of the plankton.

The skin of fatty fishes is pronouncedly higher in iodine than the meat, but with lean fishes it is rather the reverse (Lunde *et al.*, 1930).

Shellfish and selachians are found to have a higher iodine content in their edible parts than teleosts (Jarvis, 1928; Carteni and Aloj, 1934a, b). Crustaceans are in the same bracket as marine teleost fish (Jarvis, 1928; Anonymous, 1952).

F. Fluorine

The flesh of marine fishes generally contains from 0.5 to 1 mg. of fluorine per 100 g. (Tolman, 1937; Lee and Nilson, 1939; McClure 1949a, b; Monier-Williams, 1949; Truhaut, 1955). Machle *et al.* (1939) list the figure of 0.163 mg. for fish analyzed in Cincinnati, but without any other specifications as to species and size. Soviet studies by Krylova listed in Reisler (1952) give the figures shown in the next tabulation.

Fish	Fluorine (mg. %)	Fish	Fluorine (mg. %)
Soles	0.019–0.193	Shrimp	0.040
Codfish		Carp	0.032
Eleginus nawaga	0.051		
Eleginus gracilis (Far East species)	0.301–0.451	Crab	0.085

The skeleton is richer in this element than the skin. Fish eaten whole thus convey far more than is contained in the flesh.

Marine species generally have a higher fluorine content than fresh-water fish (Vinogradov and Odum, 1953).

G. Manganese

The analyses of manganese in fish meat have given highly divergent results. Orent and McCollum (1931) found from 0.01 to 0.05 mg. per 100 g., and Parks and Rose (1933) from 0.01 to 0.04 mg. But Lindow and Peterson (1927) did not find manganese in any of the analyzed species (bluefish, codfish, salmon, and halibut), while Peterson and Skinner

(1931) give values varying between 0.012 and 0.039, with 0.025 as the average. For this microelement, as for iodine, the composition of the plankton probably has a decisive influence.

Manganese is accumulated in the liver of several sea-water fishes, as the figures (Richards, 1930) given in the next tabulation prove.

Fish	Milligrams Mn per 100 g. liver tissue
Monkfish	0.076
Codfishes (av.)	0.079
Cod	0.08
Haddock	0.148
Hake	0.196

Fresh-water species contain somewhat more manganese than marine species (Parks and Rose, 1933). Only traces are reported from shrimp by Lindow and Peterson (1927), and 0.03 mg./100 g. flesh by Peterson and Skinner (1931). The amounts in other crustaceans are of the same magnitude. These latter authors found oysters exceptionally rich in this element (0.21 mg./100 g.).

H. Zinc

According to the few figures given in various publications, fish should contain from 0.7 to 3 mg. of zinc per 100 g. According to Bertrand and Vladesco (1921), the flesh of young fish has a higher zinc content than that of adult fish. They give the following values in milligrams per 100 g. flesh: tench, 6–8; herring, 2.2–5.0; *Leuciscus idus* (young to old), 1.8–14.2. The catfish is noted for its higher zinc content (Bodansky, 1920; Bertrand and Vladesco, 1921).

Table VII

Comparison of Copper and Zinc Content in Shellfish from the East and West Coasts of the United States[a]

	Number of samples	Copper[b]	Zinc[b]
California			
Oyster	8	0.39	6.50
Clam	3	0.00	1.16
Shrimp	6	1.31	1.87
Crab	9	0.25	3.10
East coast			
Oyster	3	4.39	25.99
Clam	1	0.00	7.70
Shrimp	3	1.30	1.17
Crab	2	0.58	2.06

[a] From Severy (1923).

[b] Figures indicate milligrams per 100 g. of edible flesh.

The highest zinc content is found in the gills (102.5); next comes the liver (55.5), and then the milt (43.5). These figures refer to the red snapper (Bodansky, 1921). Reisler (1952) states the presence of 1.15–7 mg. on the basis of analyses by Ivanov at the Rostov-on-Don Fish Research Station. Mollusks (Severy, 1923; Hiltner and Wichmann, 1919), crustaceans, and octopuses are, on the whole, rich in zinc (Severy, 1923; Reisler, 1952). Oysters once again seem to be the richest source (see Table VII). They are able to concentrate this metal, apparently, far in excess of their own functional requirements (Hiltner and Wichmann, 1919). *Gryphea angulata* contains about 300 mg. per 100 g. fresh weight (Simonnet, 1951, p. 105).

Interesting comparisons were made by Severy (1923) between shellfish from the East Coast of the United States and from California. Oysters and clams showed a notably higher amount of zinc in the East. The zinc content of shrimp was almost identical, whereas that of crabs was somewhat higher in the West (see Table VII).

I. Lead

Although Lampitt and Rooke (1933) did not find lead in marine animals, its presence in fish was recognized by others (Kringstad, 1935; Lunde and Kringstad, 1935; Cheftel and Pigeaud, 1937; Lepierre *et al.*, 1937; Boury, 1938). It is present in quantities ranging between 0.005 and 0.020 mg./100 g. in the whole fish. Evisceration and beheading bring about a decrease in this amount (Boury, 1938). Reisler (1952) states that the tissue of certain crustaceans contains higher quantities than are encountered in fish.

J. Arsenic

The amount of arsenic in marine fishes is greatly variable and in certain cases can attain high values. Cheftel (1950) maintains that only exceptionally does it exceed 0.05 mg./100 g. Chapman (1926), however, found 0.7 mg./100 g. in sole and still higher values in shellfish. Arsenic alone was measured by Shtenberg (1939) in the tissues of 24 fresh- and salt-water fishes (88 samples). The lowest value was obtained with *Cyprinus virula* (in Russian, "tara"), 0.062 mg./100 g. fresh weight, and the highest, 0.473 mg., in stockfish. The arsenic content is related to that of the surrounding water. The lowest values were encountered in the southern part of the Caspian, on the average 0.284 mg./100 g., and the highest, 0.88 mg., in the Sea of Okhotsk. Predaceous fishes accumulate arsenic, the catfish showing exceptionally high values.

Ellis *et al.* (1941) reported analyses of 15 species and 681 samples of fresh-water fishes. The general average was 0.03 mg. of arsenic per 100 g. (0.02 mg. after removal of the viscera). They state that on the average such fish contain 1–5 times more arsenic than vegetables and 10–20 times more than milk. Shtenberg (1939) analyzed several shellfish, both crustaceans and mollusks, obtaining values between 0.172 and 0.478 mg./100 g. fresh weight.

K. Other Microelements

There are numerous ad hoc analyses of the many additional minerals published throughout the scientific fish literature. No complete listing is sought here. Only a few findings of possible interest to future research will be quoted.

Chittenden (1877) encountered traces of lithium in the Atlantic halibut (*Hippoglossus americanus*). Recent, more accurate analyses have confirmed the presence of nickel in marine sea food, 0.7–2.9 μg./100 g. of flesh (Laevastu and Thompson, 1956). One Pacific salmon, namely *Oncorhynchus kisutch*, is particularly rich in this respect (2.9 μg.), which is in accordance with earlier Soviet reports by Maljuga (1939). A related salmonid—the smelt—is also in the higher range: 1.5 μg. (Bertrand and Macheboeuf, 1925a). Paulais (1936) discovered a concentration of nickel in the gills of fish and in the liver of mollusks. Nevertheless, the flesh contains significant quantities. Nickel presumably is essential to marine organisms, including fish. This is indicated by the high degree of concentration as compared to sea water—41,000 times greater (Noddack and Noddack, 1939). Little is known, however, as to the possible function of nickel in human physiology.

Another element, also proved essential to human beings, is cobalt. The concentration of this is given as one-tenth of that of nickel (Noddack and Noddack, 1939), but as higher by Bertrand and Macheboeuf (1925a and b). Reference is here made to the chapter on vitamins in fish (Volume I, Chapter 13), as cobalt is a cardinal part of the vitamin B_{12} molecule.

As to trace elements in general, reference may also be made to several compilations of data (Vinogradov, 1935, 1937; Vinogradov and Odum, 1953; Niemann, 1958). The following rare elements, boron, bromine, lithium, strontium, and a few others, are more concentrated in marine fish than in those from fresh waters (Vinogradov and Odum, 1953).

III. Influence of Cooking on Mineral Composition

Fish is frequently consumed cooked, so it is appropriate to discuss to what degree various cooking methods influence their mineral content.

A. Boiling in Water

From the moment when the water in which fish is cooked reaches the boiling point, the muscular fibers of the fish contract, extruding a certain quantity of water. Subsequently, the meat breaks up in flakes, and the water penetrates little by little into the openings formed. If the cooking is prolonged, this movement of water into the tissue tends to counterbalance the outflow. Under these conditions, it is obvious that the losses of weight and water caused by boiling vary greatly, not only with species —Williams (1911) noted losses in weight for 25 species within a wide amplitude of 6 to 41%—but also with cooking conditions. According to the experiences of McCance and Ship (1933), the losses of weight and water are always of the same order of magnitude—on the average, 28% for lean fish.

The mineral salts are lost especially through diffusion, which explains that the total decline in the mineral content is proportionately more important than the losses of water. According to McCance and Ship (1933), these losses amount on an average to 40–60% for chlorine, sodium, and potassium, and 20–30% for phosphorus, magnesium, and calcium.

B. Steam Heating

Fish cooked in steam lose less in weight than red meat, and this phenomenon also proceeds at a slower rate.

The loss in weight is due essentially to an outflow of water. It brings about a loss of mineral salts; but as these cannot diffuse to a surrounding medium, steam-cooked fish maintains its mineral content better than boiled fish. Chlorides, as well as other salts of sodium and potassium are, owing to their high solubility, removed, on the average, to the extent of 30%. Phosphorus, magnesium, calcium, and iron, which are partly combined with insoluble substances, particularly proteins, are eliminated to the extent of 15 to 25% (McCance and Ship, 1933). As to the total losses of mineral salts, they are proportionate to the loss of water.

C. Oven Baking and Broiling

Characterized by a continued evaporation of water from the fish with a simultaneous decrease in weight, these two ways of cooking bring about only small losses of mineral salts. As a matter of fact, the loss of water provoked by the contraction of the muscular fibers takes place only through evaporation. The fish is not in an environment which favors the diffusion of its soluble constituents to the surrounding medium.

D. Deep-Fat Frying

Deep-fat frying is the method of cooking which assures the best preservation of the nutritive value of fish. Even though it means a still more rapid evaporation of water than in oven baking or broiling—consequently, a considerable reduction in weight also (on the average 24%, according to McCance and Ship, 1933)—the losses in mineral substances are almost negligible (2–6%).

IV. Physiological Utilization of the Mineral Constituents

The only data available regarding the physiological utilization of the mineral constituents of fish refer to phosphorus, calcium, iron, and, to a minor degree, fluorine and arsenic.

A. Phosphorus and Calcium

This problem has been little studied. Lunde and Lie (1940) fed three groups of rats with diets containing identical amounts of calcium from fresh sardines, canned sardines, and powdered milk respectively. The retention of calcium, measured by the differences in the calcium content of the whole animals at the end of the experiment and their presumed content as its start, amounted respectively to 94.7, 92.1, and 93.8% of the quantities eaten by the rats.

On the other hand, Basu *et al.* (1942) included 70 g. daily of small whole fish for 4 adults subjected to a poor diet, based on rice, supplying only 200 mg. of calcium daily. The additional calcium and phosphorus thus administered amounted to 577 and 637 mg. respectively. These four individuals retained about 45% of these supplements.[1] Even though these two experiments were of limited scope, they indicate, nevertheless, that the utilization of phosphorus and calcium from fish is excellent, regardless of whether only the meat or the whole fish was eaten.

B. Iron and Copper

After breaking loose from complex iron-copper-nucleoproteins, the iron in the fish is rapidly absorbed (Saha and Banerjee, 1943) and possesses a high regenerative potency on the hemoglobin of rats, anemic due to a diet rich in milk (Saha, 1941c). But the other constituents of the complex have their influences: as a matter of fact, the elimination of copper clearly diminishes the antianemic action of this complex, and the iron-copper association, separated from the protein fraction, has a hematopoietic power inferior to that of the complex (Saha, 1941c). Due to the iron content fish is most effective in regenerating hemoglobin in cases of anemia (Whipple, 1935).

As a copper source, oysters are exceeded only by calves' liver, which explains their therapeutic value. Several studies report on the curing of milk anemia in rats through oysters (Levine *et al.*, 1931). This is attributed to their high content of iron and zinc, but primarily copper. In spite of the relatively high copper content of oysters, no harmful effects have been observed, nor is there any excessive accumulation of copper in the body when large quantities are consumed (Coulson *et al.*, 1934).

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[1] This proportion is rarely exceeded by adults, even with milk.

C. OTHER MINERALS

Fish, particularly of marine origin, is equally unique as a source of fluorine as it is with regard to iodine. Fish, containing on the average 5 p.p.m., is far ahead of most other foods (Lee and Nilson, 1939; McClure, 1949a, b). This is even in excess of the 2 p.p.m. level which is considered to cause mottled teeth. But the fluorine of fish is bound organically and consequently not fully utilized by the human body (Lee and Nilson, 1939).

On the island of Tristan da Cunha, where the drinking water is deficient in fluorine (less than 0.2 p.p.m.), Sognnaes (1941), however, observed in no less than 16% of the inhabitants fluorose dental lesions which he attributed to an excessive consumption of fish (240–390 g. per day and person). Further research is needed on this matter. In the proportion in which fish normally is eaten, it is, nevertheless, an important source of fluorine, favorably counteracting dental caries (Cox, 1952).

The arsenic question was studied by Chapman (1926) and Coulson *et al.* (1935). According to this author, the arsenic of marine animals enters into an organic bond, from which it is not liberated during the process of digestion. The existence of such compounds might explain the absence of danger from too large doses of the arsenic that some fish, crustaceans, and mollusks seem to contain.

V. The Importance of Fish as a Source of Minerals

A. GENERAL

The mineral composition of cooked fish meat as compared to the minerals supplied by an average diet (Table VIII) shows that fish is: an important source of iodine, and maybe of fluorine (if this latter is well utilized by the organism, which is not certain); a significant source of phosphorus, potassium, iron, and copper; short in chlorine and sodium (in spite of the relative richness of sea water in sodium chloride) and, with certain exception, in calcium also.

Although their mineral composition has been little studied, the viscera seem superior to the meat as a source of phosphorus, calcium, and iron.

Whole fish is superior to the flesh alone as a source of phosphorus and, above all, calcium. In the fresh state, 100 g. of fish of the smaller species seems capable of totally satisfying the calcium need of the adult (about 800 mg. daily).

TABLE VIII
NUTRITIVE IMPORTANCE OF MINERALS IN FISH FLESH

Element	Average content (mg./100 g.)		Adult requirement (mg./day) according to National Research Council (4)	Quantity normally consumed (mg./day) (5)	Percentage of (4) or (5) supplied by 150 g. cooked fish flesh
	Raw fish (2)	Cooked in water (3)			
Chlorine	100	50	—	6000	1
Sodium	60	30	—	4000	1
Potassium	400	200	—	3000	10
Phosphorus	220	165	1200	—	20
Calcium	30	22	800	—	4
Magnesium	30	22	—	300	11
Iron	0.8	approx. 0.6	12	—	8
Copper	0.25	—	—	2.5	—
Iodine	0.17	—	0.15–0.30	—	—

For a general discussion of the nutritive aspects of fish in general and minerals in particular, reference is made to Gimenez (1934), Quagliarello (1934, 1936), Ranganathan *et al.* (1937), and Causeret (1950a, b).

B. FISH IODINE, GOITER, ETC.

As indicated earlier, the only rich source of iodine commonly included in the human diet derives from marine animals. Inclusion of fish in the diet once daily provides an abundant iodine intake. It is probably this source that, more than any other, accounts for the finding that populations near the sea receive more iodine than those farther inland. The problem of obtaining sufficient iodine from food of nonmarine origin may be seen from values shown in Table IX. Iodine-rich seaweed is an abundant source on a limited scale for some peoples.

TABLE IX
APPROXIMATE QUANTITY OF COMMON FOODS NEEDED TO SUPPLY 100 μg. OF IODINE[a]

Food	Pounds of fresh product
Vegetables, fruits	10
Cereals, grains, nuts	8
Meat, fresh-water fish, fowl	6
Milk	4
Eggs	2
Marine fish	0.3
Shellfish	0.2

[a] From Astwood (1955).

Japan is nongoitrous as compared with other countries. This would appear to be due not only to proximity to the ocean, which would imply a high content of iodine for much of the vegetation, but also to the Japanese diet, which is extremely high in fish, marine algae, and sea food of all kinds. Even in the mountainous valleys among 20,000 inhabitants, only four goiter cases were encountered (McClendon, 1939). In a similar way, the coastal area of mid-China is free from goiter because of marine foods (Adolph and Whang, 1932), and the case is similar in the nongoitrous province of Buenos Aires, as compared to the Andean province of Salta (Mazzocco, 1929).

On the other hand, the Formosans, whose food habits are like the Chinese rather than the Japanese, with less sea food, are highly goitrous, even though the soils of Formosa are from the same geological formation as those of Japan. Goiter is common in Thailand, Sumatra, Java, Borneo, and Bali (Gilbert, 1957).

Canned salmon has been studied as a prophylactic against goiter (Jarvis *et al.*, 1926). The same would undoubtedly be true of other iodine-rich fish varieties. No studies, however, are available on the degree of absorption of iodine from diverse fish sources.

United Kingdom studies (Anonymous, 1952) in urban working-class families revealed that the average food intake provided less than half of the weekly iodine requirements. Only 565 mg. was conveyed through food. Of this quantity, fish accounted for no less than 35% (198 mg.)—the single food commodity providing most iodine (Table X) in spite of the per capita consumption of the item not being particularly high.

TABLE X
ESTIMATED IODINE INTAKE IN CERTAIN UNITED KINGDOM FAMILIES

Food	Milligram iodine per week	Consumption per capita per week
Fish	198	8.4 oz.
Cereals	113	85.4 oz.
Milk	95	4.8 pints
Vegetables	82	99.9 oz.

A problem that has been widely discussed but not too profoundly studied is to what degree iodine of sea food might enter into foods of animal origin through foodstuffs of this nature. The composition of meat and milk does not seem to be influenced, while eggs largely increase their iodine content through the use of marine fish meal or fish scraps in the poultry ration (Almquist and Givens, 1935).

C. LOW-SODIUM DIETS

There has been some doubt expressed about the advisability of utilizing fish in sodium-restricted diets prescribed to persons suffering from hypertension. This is entirely unfounded even in the case of salt-water fish, in spite of their inhabiting waters containing so much sodium chloride. Although salt-water fish average higher in sodium content than the fresh-water varieties, they still stand out favorably in respect to the values approved by dietetic experts. A low-sodium diet should contain less than 100 mg. of sodium per 100 g. food, and preferably less than 60 mg. None of the individual species—of either salt- or fresh-water fish—contains as much sodium as this permitted maximum (Thurston, 1958). Even the species having the highest individual sodium values were well suited for inclusion in low-sodium diets, since no specimens contained as much as 100 mg. of sodium per 100 g. of flesh. Since fish vary markedly in flavor and texture, this offers the possibility of a diversification in low-sodium diets.

It is evident that the addition of salt would bring about a tremendous change in the sodium content of this food. Low-sodium packs have to be *au naturel.* Canned salmon and tuna have been studied in this respect (McBride and MacLeod, 1954; Murray *et al.,* 1954). To get some idea of the structure of each of the readily separable constituents present in a can of fish with regard to the total sodium and potassium content, the bones, liquid, and drained, bone-free flesh of fish canned without added salt were analyzed. Although on a unit-weight basis bones are relatively high in sodium and potassium, their total weight, and hence their contribution to the total sodium and potassium content of the cans, is small. Approximately 25% of the total sodium and potassium salts is present in that portion of the liquid in the cans which can be readily drained from fish, thus allowing still greater reduction in the amount of sodium.

The addition of salt to the boiling water in preparing fish naturally will greatly increase the sodium content. In some cases there is the practice among fishermen of throwing salt on the fish that reach the deck in order to retard spoilage somewhat. A similar practice is on occasion employed in the icing. In both cases sodium values increase far above the natural level. In the making of dried cod or lingcod salt is frequently used as a drying agent. Consequently, codfish shows high sodium values. Brine storage greatly increases the sodium content of pink salmon (Thurston and Groninger, 1959).

D. Bone Eating

Latin America, where the dairy products have only limited space in the diet, the intake of calcium through fish, eaten whole—fresh, or preserved through drying, salting, or smoking—can thus supplement the vegetable foods and ensure an improved bone development (Wood, 1947).

Merely cooking the fish with the bones provides calcium. When cuts of *Stromateus niger* ("bawal") and *Lates calcarifer* ("kakap") were boiled with the bone, the calcium content of the flesh, in relation to the dry matter, was increased by 75%, as compared with that prepared without bone. Phosphorus, however, was reduced by about one-third (van Veen, 1948).

In this respect the superiority of fish is most evident when it is consumed whole, as small, deep-fried dishes or canned sardines. The calcium of the bones, mainly represented by calcium phosphates, is well utilized by the body (Basu *et al.,* 1942).

E. Fish in Relief Plans

Efforts have been made in numerous countries for the past ten years, often with the technical support of international organizations (FAO, WHO), to develop ocean fisheries or the cultivation of fish and to expand the consumption of small fish eaten whole in the form of pastes, sauces, etc. These efforts are of great value, not only to ensure the prevention of kwashiorkor and other types of protein malnutrition, but also to improve the calcium intake of the people. In 1948, a regional nutritional committee for South and Southeast Asia which met at Baguio (Philippines) on the initiative of the FAO, recommended a general formula for inexpensive meals, comprising especially small fish eaten whole as a source of calcium. Whenever this formula has been applied, it has given good results.

Dried fish was an important part in the "usual village diet" in a Belgian Congo study contributing substantially in providing both calcium and phosphorus (Holemans and Lambreches, 1958).

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CHAPTER 6

Changes in Nutritive Value Through Handling and Processing Procedures

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I. Introduction

Information concerning the nutritive value of fish during various handling, transportation, storage, cooking, and processing procedures is scattered and, in general, rather fragmentary. In fact, superficially at least, it may appear that more attention has been paid to the loss of nutritive value of fish materials resulting from their processing for animal feeding than there has to their preparation for human foods. If this is so, it is undoubtedly related to the rather adverse processing and storage conditions to which fish materials intended for animal nutrition are exposed. Here an attempt will be made to consider all the various procedures which may, singly or collectively, impair the nutritive value of fish for human nutrition. Naturally, the indirect loss of fish materials of high nutritive value by bacterial spoilage, as discussed elsewhere, is almost certainly more important than that from all factors to be referred to in this section.

II. Physical Losses in Round and Dressed Fish

Over three decades ago it was reported that boxed, iced fish had at first all gained weight slightly, and that this increase was maintained in the upper layers of fish, while there was a gradual weight loss in the lower layers. Some loss of organic nitrogenous constituents and inorganic salts was observed, especially in the lower layers of fish (Almy *et al.*, 1923). Flesh of iced cod was found to lose from 28 to 60% of the free amino acids, and from 1.8 to 3.8% of the protein (Dyer and Dyer, 1947). From a thorough investigation of weight losses occurring in commercially important North Sea fish iced on trawlers, Cutting (1951) concluded that weight losses were probably due entirely to pressure exerted on the lower layers of fish. Thus, iced fish at the top of the pens, and also boxed fish, gained weight at first and eventually tended to lose weight. On the other hand, in extreme instances, fish in the lower layers of ice lost 17–18% of their weight after 16 to 18 days in ice. Nitrogen losses, though not determined, would undoubtedly be considerable from the fish in the lower layers of ice. On voyages of 2 to 3 weeks' duration, average weight losses of 6 to 7% were observed. Recent studies with iced noneviscerated Pacific sockeye salmon have shown that these fish lose 2.4% in weight and about 2.5% of their total protein (Barker and Idler, 1955).

In recent years increasing interest has been evidenced in the possibility of commercial application of early studies concerning refrigerated sea-water storage of fish (Tarr and Harrison, 1957). In this medium fish invariably gain weight, and the weight increase will depend on obvious factors such as size of fish, fattiness, and whether or not they are eviscerated. The extremely limited data presently available concerning these weight increases indicate that certain species of Pacific salmon stored at —1° in refrigerated sea water gain from 0.2 to 3.7% in weight and lose from 1.2 to 3.3% of their total protein (Barker and Idler, 1955). White-fleshed, nonoily fish such as eviscerated cod may gain appreciably more weight, and unpublished studies (Southcott, Baker, and Tarr) have indicated that eviscerated Pacific ling cod gain 4–5% in weight after about 2 weeks in this medium. It would seem probable that some of the protein which is lost from iced fish, or from fish stored in refrigerated sea water, may come from the external slime of the fish.

III. Physical Losses during Processing

In this section the term "processing" has been loosely used and covers all phases of fish preparation for human food as described in the following sections. Reay *et al.* (1943) have reported the yields of edible flesh which result in filleting procedures.

A. In Filleting and Similar Operations

Losses which occur in fish fillets and steaks are largely or entirely due to formation of free liquid or "drip." This loss of free liquid occurs to some extent in unfrozen fish, but is certainly greatly accentuated by freezing and subsequent thawing, and the early literature on this subject has been reviewed (Tarr, 1942). It has long been known that light brining of fish fillets tends to prevent formation of drip, especially in those which are frozen and subsequently thawed (Tarr, 1940; Tarr and Sunderland, 1940a, b; Stansby, 1956). The mechanism by which salt exerts its drip-preventing function is probably due to the osmotic effect exerted by the sodium proteinates of the fish muscle. It has been shown that both pH and sodium chloride markedly favor swelling of fish muscles above the isoelectric zone, and especially between pH 6 and 8. The amount of drip formed in stored muscles of different fish varies very greatly. Thus, with some species of Pacific flounders weight losses of from 10 to 15% were recorded after 10 days' storage at 0°C. With other fish such as, for example, certain Pacific salmon species, much less liquid forms. Though extensive protein losses obviously must occur as a result of drip formation, there does not appear to be much information concerning the magnitude of such a loss. Seagran (1958) has reported that a "drip" liquid obtained by centrifuging defrosted fish muscle contained 4% of protein. As mentioned above, a light brining procedure, in which the flesh of the fish takes up from about 0.5 to 1% of salt, largely or entirely eliminates exudation of free liquid after the fish have been frozen and thawed. This procedure is the only one which has so far been found practicable to prevent drip formation. However, this brining procedure undoubtedly accelerates development of oxidative rancidity in frozen fish which have been so treated (Tarr, 1942, 1955b). Lightly brined fillets should, therefore, be stored under conditions which are designed to minimize development of oxidative rancidity.

B. In Freezing and Cold Storage

Frozen fishery products are susceptible to a number of undesirable alterations which include physical desiccation, denaturation of the muscle protein myosin, and development of oxidative rancidity, but only too little is known regarding the direct effect of these changes on the nutritive value. All of them certainly have an indirect effect in that the acceptability of any affected product is lowered. Nutritive value of fish, as determined by its gross chemical composition, in total solids, water, soluble nitrogen, coagulable nitrogen, noncoagulable nitrogen, ammonia, lipids, and reducing substances is not altered (Smith, 1913; Perlzweig and Gies, 1913), or altered to a negligible extent (Clark and Almy, 1920) by prolonged storage in the frozen state.

Desiccation of frozen fish in cold storage rooms is a serious problem with ice-glazed unwrapped fish. The important effects on nutritive value here are probably entirely indirect, for loss of surface water is accompanied by undesirable external appearance such as "freezer burn," "rusting," and loss of weight. There are two general methods by which this desiccation may be minimized or prevented. Proper design of cold storage rooms in order that as high a relative humidity as possible is maintained is one of the most important (Huntsman, 1931; Lentz, 1955; Young, 1932, 1933, 1934). There is considerable information in the literature concerning the proper glazing of fish in such a manner as to produce a glaze which has noncracking or "reducing" properties. A very large number of both inorganic and organic materials has been studied; the use of some of these has been strongly advocated, and in a few instances some have been applied (Young, 1935; Bedford, 1936a, b, c; Lemon, 1932; Pottinger and Miyauchi, 1956; Tarr, 1948, 1955b). In addition there are a number of United States and other patents in this respect. It is doubtful whether there is any single ideal glazing substance. Many of them which have desirable noncracking properties produce a somewhat opaque glaze which is considered undesirable by some processors.

In fillets and steaks the great desirability of minimizing development of oxidative rancidity by such measures as storage in a vacuum, or in an inert atmosphere such as nitrogen, by covering the fish with water, by good glazing procedures, by use of various antioxidants, or by adequate packaging in oxygen- and moisture-vapor-impermeable materials has been stressed by a number of different investigators (Bucher, 1944; Tarr, 1948, 1955b; Pottinger and Miyauchi, 1956). It is probable that development of oxidative rancidity has an adverse effect on fish, since oxidized fats are known to have a marked destructive effect on certain of the essential growth factors, such as vitamin E, vitamin A, and biotin. Moreover, they may exert a direct toxic action and destroy certain enzyme systems (Holman, 1954).

Though it was long assumed that the denaturation of the muscle protein myosin, as judged by its decreasing solubility in neutral salt solutions of relatively high ionic strength, was directly related to the organoleptic toughness which developed during low temperature storage at temperatures between about —30 and —5°C. (Reay, 1933, 1934; Dyer, 1954), this relationship has been seriously disputed recently. Data indicate that at —20 and —30°C. fish flesh may become markedly toughened organoleptically but that myosin denaturation as measured above may not be affected (Ironside and Love, 1956; Luijpen, 1957). However, there is no indication that this organoleptic toughness has any adverse effect at all upon the nutritive value of the fish.

C. In Brining, Salting, and Smoking

It is known that the curing of fishery products during salting or procedures which involve salting such as smoking, is usually accompanied by protein losses. Reay (1936) made a thorough study of the transfer of salt and water in fish held in sodium chloride solutions of different concentrations, and in dry salt. He found that the loss of fat was negligible, but that protein losses ranged from 1% in dry salted herring to as much as 5% in herring salted by brining. A somewhat similar study was made by Sigurdsson (1945). According to Shewan (1949), weight losses caused both by brining and by subsequent desiccation during smoking of fish vary from 8 to 30%, and some protein is also lost during this form of processing. Average weight losses in haddock during smoking were reported as being 17.1% by Griffiths and Lemon (1934).

D. In Canning

The losses of nutritive materials which occur in fish during canning procedures are usually of the types which are economically unavoidable and are occasioned by such factors as living standards and market demand. These losses are real as far as direct human nutrition is concerned but the discarded materials are often processed to yield products which can be used in the feeding of farm or domestic animals, or as fertilizers. One of the outstanding reported losses of valuable nutritional material is that which occurs in connection with the Alaska salmon canning industry where conditions have rendered it economically impossible to prepare products such as fish meal from the discarded offal and trimmings. A survey made about 1947 showed that about 100 million pounds of salmon "collars," tails, hearts, livers, eggs, milts, viscera and trimmings from the "iron chink" were discarded annually (Anonymous, 1947). Salmon egg protein (Seagran *et al.*, 1954) and fish liver protein (Deas and Tarr, 1949) are excellent sources of amino acids, and the visceral organs generally of vitamins A, D, and the B complex (Grangaud, 1950). The total weight losses which occur during the cleaning of fish and shellfish for canning have been tabulated by Tressler and Lemon (1951, pp. 452–458).

It is probable that nutritional losses occurring in canned fish products during normal storage periods are negligible, but further losses often occur before final consumption. Free liquids, oil, and bone may be discarded. The free liquid may amount to about 20% of the weight of the fish (McCance and Shipp, 1933; Tarr, 1941) and contain some noncoagulable nitrogenous material such as free amino acids. The oils usually contain vitamin D and are excellent foods, and the bone is a good source of calcium and phosphorus. The aqueous liquid in canned fish contains from 1.01 to 1.97% of the total nitrogen of the product (Ivanov, 1937). If the nitrogenous material in the free liquid of canned fish has somewhat the same general composition as does fish press water (stickwater), it may not be a very good source of essential amino acids (Lassen and Bacon, 1946; Ney *et al.*, 1950).

E. In Dehydration

The whole subject of the dehydration of fish has been recently summarized thoroughly (Cutting *et al.*, 1956). Though a considerable amount of experimental work has been conducted, only a very small quantity of the commodity has ever been produced commercially. The presently accepted commercial procedure for production of dehydrated fish involves mincing raw fillets, precooking of this mince by steaming, and subsequent drying of the minced material in an air-flow drying apparatus. The liquor which exudes from the fish during cooking, which is partially actual exudate from the fish and partially steam condensate, is frequently discarded. This liquid usually contains 4% solids which consist of some protein and about half of the water-soluble constituents of the flesh. Its actual nutritive value has apparently not been determined, but presumably would be little better than that of ordinary "stickwater." It can be concentrated and added back to the flesh before drying but apparently it does not improve the organoleptic quality. A good deal of the fish may be lost in handling during the dehydration process, and losses have been reported which range from 1.4 to 5.3% with herring and kippers to 6.3 to 12.3% with ordinary cod or smoked cod. Naturally these losses depend a good deal on the efficiency of the process and the care taken in handling the fish. The need for eliminating as much moisture as possible in the dehydrated products, to avoid possible brown discolorations due to Maillard reactions, was stressed by Stansby (1945). Cutting *et al.* (1956) emphasized the need for nitrogen packaging to counteract fat oxidation. It has been demonstrated that Maillard reactions may occur in heated and dried fish (Tarr, 1950, 1954). These reactions, if they occur in dehydrated fish, could cause a significant decrease in its nutritive value by decreasing availability of essential amino acids. However, feeding trials of certain dehydrated fish preparations indicated no loss in nutritive value or digestibility (Martinek and Jacobs, 1943), though 50% of the thiamin and 65% of the riboflavin were destroyed (Stansby, 1945).

F. In Cooking

McCance and Shipp (1933) reviewed the early literature concerning losses in weight and in nutritive materials which occur during cooking of flesh foods. They carried out a very thorough experimental examination of all factors which influence loss of weight of fish on cooking, including effects of temperature, pH, and postmortem age, and made extensive analyses of the exuded liquids for salts, fats, and nitrogenous constituents. The losses naturally differed with different cooking methods, but above 60°C. there was, under any cooking conditions, a shrinkage of protein and an expression of liquid. These losses tend to be greater with materials held for several days after death, and cooking fish muscle by boiling in dilute acetic acid results in marked increases in loss of calcium and magnesium, but usually in not such a marked weight loss as does boiling in water. Cooking of white-fleshed fish by steaming or pressure cooking resulted in the following average losses (%): total nitrogen, 7.5; protein nitrogen, 5.3; nonprotein nitrogen, 29; purine nitrogen, 19.5, and fat, 5.3. Losses of Na^+, K^+, Cl^-, total P, Ca^{++}, Mg^{++}, and Fe^{+++} ranged from 19 to 32%. Comparative experiments with herring and catfish showed that losses of weight were greater when the fish were fried in fat rather than cooking by boiling or steaming, due to greater evaporation of water. On the other hand, losses of the nutrients were very much lower with the frying method. As an example, the following percentage losses due to boiling or steaming as compared with frying were reported respectively: total nitrogen, 5.6–9.9 and 0.05–0.1; purine nitrogen, 12.7–17.6 and 1.7–2.4; nonprotein nitrogen, 23.6–35.0 and 1.1–2.1. Mineral element losses were also considerably smaller with the frying procedure. In general, 95% of the loss of weight on steaming white-fleshed, nonfatty fish is due to loss of water, and the remainder to nitrogenous constituents, fat and salts.

Tarr (1941) observed weight losses of from 15.8 to 19.5% in fresh halibut steamed at 100°C., and from 18.6 to 23.3% at 120°C. These losses were much smaller (8.5–12.1%) when frozen, thawed halibut was cooked similarly. Baker briefly reviewed the subject of cooking losses in fish (1943). Charley (1951) studied the effect of different oven temperatures on the palatability of baked salmon steaks. Cooking to an internal temperature of 70°C. was insufficient to cook the fish adequately, and fish cooked to internal temperatures of 75 or 80°C. at different oven temperatures were conceded to be satisfactory. At an elevated oven temperature (260°C.) there was considerable loss of weight due to "spattering" and drip loss. Charley and Goertz (1958) found that approximately 1-kg. portions of salmon lost 14.34–18.64% in weight on baking to an internal temperature of 70°C. at oven temperatures of between 177 and 260°C., most of the loss being due to evaporation and only a small proportion to drip. Losses of actual nutrients were not reported in any of these studies.

IV. Chemical Losses Due to Destruction or Removal of Nutrients

A. IMPAIRMENT OF PROTEIN VALUE

Nutritional studies on fish proteins have been confined very largely to the muscle proteins and there is only scattered information concerning nutritive value of other fish proteins. The various fish muscle proteins have been thoroughly described in a recent review (Hamoir, 1955). The nitrogenous fraction of muscles of teleost fish contains, on the average, about 65% actomyosin, 18% proteins extractable by neutral salt solutions of low ionic strength, 3–4% of "stroma" proteins and 14% of nonprotein nitrogen. Naturally, there are considerable variations with species, season, and even within the muscle itself. When considered collectively, fish muscle proteins are at least of equivalent, and probably of higher, nutritive value than those of commonly consumed meats obtained from cattle and hogs (Beveridge, 1947; Geiger, 1948; Jacquot and Creac'h, 1950; Tarr, 1953). This is probably explained by the fact that fish muscles normally contain less "stroma" protein of low nutritive value than do the muscles of cattle. It has long been known that fish flesh proteins are an excellent source of the essential amino acids, though a survey of the literature made in 1949 (Deas and Tarr) showed that there were wide discrepancies in the values reported by different investigators. These discrepancies were probably due to the difficulties of obtaining accurate values with the older methods of amino acid assays. With the advent of the more sensitive microbiological and quantitative chromatographic methods for determining amino acids, there has been in general a much closer agreement in the results obtained by different investigators (Block and Bolling, 1951). These methods have enabled valuable surveys to be made of the amino acid composition of edible fish proteins which have been subjected to different commercial treatments. For further discussions of the nutritive aspects of fish proteins see Chapter 2.

Dunn and his collaborators (1949) published the results of amino acid analyses carried out in two different laboratories using identical samples of the edible portion of fresh raw, freeze-dried, and frozen Pacific sardines (Table I). There was an extremely close agreement in the values obtained in the two laboratories and the treatments had no significant effect on the amino acid composition of the products. In this particular survey the results were based on the dry weight of the sample instead of as the per cent of the protein (grams per 16 g. of nitrogen).

Aspartic acid, glutamic acid, and glycine normally account for about 30% of the total amino acids in flesh proteins, and it is therefore interesting that the amounts of these two were found by Dunn *et al.* (1949) not to differ significantly in raw, precooked, and canned fish samples

TABLE I[a]
PERCENTAGES[b] OF AMINO ACIDS IN IDENTICAL SARDINE SAMPLES ASSAYED IN TWO LABORATORIES

	Fresh (acid hydrolyzate)[c]							
	Sample No. 1		Sample No. 2		Lyophilized[d]		Frozen[d]	
Amino acid	A[e]	B[e]	A	B	A	B	A	B
Arginine	3.1	3.1	3.1	3.1	2.9	3.1	2.9	3.2
Aspartic acid	5.1	—	5.0	—	4.7	—	4.8	—
Glutamic acid	7.0	—	7.0	—	6.7	—	7.1	—
Glycine	2.9	—	2.9	—	—	—	—	—
Histidine	3.0	2.9	3.0	3.0	2.8	2.7	2.8	2.8
Isoleucine	2.7	2.7	2.6	2.8	2.5	2.5	2.6	2.5
Leucine	4.1	3.9	4.0	3.9	3.8	3.8	3.9	3.8
Lysine	4.6	4.3	4.6	4.2	—	4.3	4.5	4.4
Methionine	1.7	1.3	1.6	1.2	1.5	1.5	1.6	1.6
Phenylalanine	2.1	2.1	2.1	2.2	2.0	1.9	2.1	2.0
Threonine	2.4	2.6	2.4	2.6	2.2	2.4	2.3	2.4
Tryptophan	0.5	0.5	0.5	0.5	0.6	0.4	0.6	0.4
Valine	3.0	3.0	3.0	3.1	2.9	2.7	2.9	2.8

[a] From Dunn *et al.* (1949).

[b] Calculated as per cent of dry weight.

[c] Samples prepared at University of California, Los Angeles.

[d] Samples prepared at University of California, Los Angeles, but hydrolyzed independently in the two laboratories.

[e] Microbiological assays carried out at: A, University of California, Los Angeles; B, University of Wisconsin.

which they examined (Table II). When a number of very different canned fish products were analyzed for their content of the ten essential amino acids in the two widely separated laboratories referred to previously, it was found that there were no important differences and that all products contained these amino acids in comparatively large amounts (Table III) (Neilands *et al.*, 1949).

The studies referred to above showed that lyophilizing, freezing, and canning fish did not reduce the amount of amino acids present as determined by using chemical hydrolysis before carrying out the microbiological assays employed. Unfortunately, such results cannot be considered as complete and final proof of the retention of full nutritive value of such fish products. Thus it has been shown (Clandinin, 1949; Tarr *et al.*, 1954; Bissett and Tarr, 1954) that fish meals which are seriously overheated, and which are of poor nutritive value for chicks, have a normal essential amino acid composition as indicated by microbiological assays carried out on the chemically hydrolyzed product. On the other hand, assays of enzymic hydrolyzates of these meals show that they are seriously lacking in essential amino acids which are available to the animal. Though it would seem highly improbable that any serious impairment of amino acid nutritive value of fish products would result through canning procedures, it is possible that a very slight decrease could occur. Thus, Marks and Nilson (1945) in a careful study of the effects of different cooking methods on the nutritive value of cod flesh

TABLE II[a]

ASPARTIC ACID, GLUTAMIC ACID, AND GLYCINE IN FISH SAMPLES[b]

Sample[c]	Aspartic acid	Glutamic acid	Glycine
Atlantic mackerel, raw	9.2	13.1	5.7
Atlantic mackerel, processed	9.3	13.3	7.0
Atlantic mackerel, raw	9.2	13.2	6.2
Atlantic mackerel, processed	9.0	12.4	6.7
Pacific mackerel, raw	9.0	12.8	5.6
Pacific mackerel, processed	8.3	13.0	5.3
Pacific mackerel, raw	9.0	12.8	5.8
Pacific mackerel, processed	8.5	12.8	5.4
Pacific sardines, raw	8.7	12.3	5.1
Atlantic sardines, raw	9.2	13.3	5.6
Atlantic sardines, raw	7.7	11.2	5.3
Atlantic sardines, processed in oil	9.2	13.2	6.4
Pacific sardines, raw	9.2	13.2	6.6
Pacific sardines, processed in tomato sauce	8.0	13.3	5.6
Pacific sardines, raw	8.9	11.5	5.2
Pacific sardines, precooked	9.6	13.5	5.8
Pacific sardines, processed in tomato sauce	8.8	12.0	4.9
Atlantic fish flakes, raw	10.2	15.2	5.2
Atlantic fish flakes, processed	9.8	14.6	5.0
Atlantic fish flakes, raw	9.0	13.6	4.6
Atlantic fish flakes, processed	10.1	15.1	5.7
Pacific salmon, raw	9.1	13.2	6.0
Pacific salmon, processed	9.3	13.6	6.2
Pacific salmon, raw	9.0	13.0	6.4
Pacific salmon, processed	8.8	12.6	5.0
Tuna, raw	8.3	13.0	4.6
Tuna, precooked	8.8	13.6	4.3
Tuna, processed in oil	8.4	13.5	4.5
Tuna, raw	8.4	13.5	4.5
Tuna, precooked	8.2	11.8	5.0
Tuna, processed in oil	8.6	12.2	4.5

[a] From Dunn *et al.* (1949).

[b] Per cent of protein = N × 6.25.

[c] Samples in each group were all from the same original fish sample and are therefore strictly comparable. The term "processed" indicates commercial canning.

for rats, concluded that prolonged cooking at an elevated temperature (35 min. at 450°F.), or long holding of normally cooked samples (30 min. at 170°F.), occasioned small, though significant decreases in their nutritive value.

The first detailed publication concerning the effects of different processing treatments on the amino acids of fish was published by Lopez-Matas and Fellers (1948). They found no appreciable difference in the essential amino acid composition of frozen, broiled, and canned swordfish, but observed that for 8 out of 10 of these essential amino acids, lower results were obtained when dehydrated fish material was analyzed. Since chemical methods of hydrolysis were used to release the amino acids prior to the microbiological assays, it would appear that, in their dehydrated preparation, certain of the amino acids had entered into Maillard reactions which had proceeded to such an extent that they were no longer released by chemical hydrolysis. In this connection it is of interest that Deas and Tarr (1949) found that a sample of rock cod which had been air-dried at a fairly high temperature contained an unusually low proportion of tryptophan. There would seem to be a possibility that slight losses in the nutritive value of fish proteins could be occasioned by Maillard reactions (Tarr, 1948, 1954) or other browning reactions (Venolia *et al.*, 1957) occurring during canning or drying processes; perhaps this possibility should be investigated further. Freezing did not affect the nutritive value of crab meat as determined biologically (Watson and Fellers, 1935).

B. Impairment of Vitamin Value

It is only within the last two decades that many of the vitamins have been discovered and reliable chemical, biological, or microbiological methods of assay for them established. In 1948 the National Research Council of the United States established the following human daily vitamin requirements, the amounts varying according to age, sex, etc.: vitamin A, 1,500–9,000 I.U. (0.40–0.7 mg.); vitamin D, 400 I.U.; thiamine, 0.4–1.8 mg.; riboflavine, 0.6–3.0 mg.; niacin, 4–18 mg.; and ascorbic acid 30–150 mg. Though the human requirement for pantothenic acid, folic acid, pyridoxine, biotin and vitamin B_{12} (cobalamin) has not been definitely established, the distribution of these vitamins in fresh and processed fish materials will also be referred to. Previous reviews concerning the distribution and stability of certain vitamins in fishery products were made by Lovern (1943), Tarr (1955a), Grangaud (1950), and Kühnau (1956). It is regrettable that only in some instances have investigators carried out comparative vitamin assays on raw and processed samples prepared from identical materials. For convenience the

TABLE III[a]
ESSENTIAL AMINO ACID CONTENT OF FISH PRODUCTS (PER CENT OF PROTEIN)

Amino acid	Atlantic mackerel				Pacific mackerel				Atlantic sardines				Pacific sardines			
	Raw		Processed		Raw		Processed		Raw		Processed in oil		Raw		Processed in tomato sauce	
	A[b]	B[b]	A	B	A		B		A	B	A	B	A	B	A	B
Arginine	5.6	5.6	5.8	5.8	5.4	5.2	5.6	5.6	5.9	4.8	6.1	5.5	4.9	6.0	5.2	4.5
Histidine	4.2	4.1	3.7	3.7	5.6	6.0	5.2	5.3	2.4	2.3	2.3	2.4	4.6	5.5	5.0	4.3
Isoleucine	5.5	5.0	5.5	4.8	4.7	5.0	4.9	5.4	5.3	3.8	5.3	4.5	4.2	5.2	4.5	4.3
Leucine	6.9	7.0	7.2	7.4	6.7	8.1	6.9	7.4	7.1	6.2	7.3	7.4	6.5	8.2	7.3	7.3
Lysine	8.0	8.6	7.7	9.0	8.7	8.3	9.1	8.2	7.6	7.5	7.5	8.9	8.6	9.0	9.7	7.2
Methionine	2.6	2.8	2.6	2.8	2.8	2.8	2.9	2.7	2.5	2.6	2.7	3.0	2.7	2.7	2.9	2.4
Phenylalanine	3.3	3.8	3.6	3.6	3.7	3.9	3.8	3.9	3.5	3.2	3.5	3.7	3.8	4.2	3.7	3.4
Threonine	4.6	5.5	4.7	6.3	4.5	4.6	4.3	4.7	4.3	4.8	3.9	5.3	4.3	4.6	4.2	3.6
Tryptophan	0.9	0.9	0.9	0.3	1.1	1.0	1.2	1.0	0.8	0.7	0.7	0.8	0.9	1.0	1.0	1.1
Valine	5.6	5.7	5.2	5.4	4.8	5.6	4.7	5.5	5.2	4.2	5.2	5.2	4.8	5.6	5.0	5.3

[a] From Neilands *et al.* (1949).

[b] Assays carried out at: A, University of California, Los Angeles; B, University of Wisconsin.

TABLE III[a] (*continued*)

Amino acid	Atlantic fish flakes				Pacific salmon				Pacific tuna					
	Raw		Processed		Raw		Processed		Raw		Precooked		Processed in oil	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Arginine	6.1	6.1	6.2	5.8	5.8	5.5	5.9	5.5	5.7	5.2	5.6	4.6	5.6	5.0
Histidine	2.1	2.1	2.1	2.1	2.7	2.7	2.7	2.7	6.0	5.6	5.4	5.1	5.6	5.2
Isoleucine	6.1	5.2	6.3	4.7	4.7	5.4	4.9	5.0	4.8	4.4	5.1	4.8	5.3	5.4
Leucine	8.3	8.2	8.2	7.8	6.8	7.2	7.2	7.6	7.2	6.9	7.2	7.2	7.5	7.2
Lysine	8.5	10.0	8.7	9.4	7.5	8.4	8.0	8.5	8.3	8.6	8.0	8.1	8.5	8.1
Methionine	2.7	3.4	2.6	3.2	3.0	2.8	3.1	3.0	3.0	2.8	2.9	2.7	2.9	2.6
Phenylalanine	3.8	3.9	3.7	3.7	3.4	3.7	3.7	3.7	3.6	3.4	3.8	3.3	4.0	3.7
Threonine	4.4	6.0	4.3	5.8	4.0	4.0	4.0	4.6	4.5	6.3	4.7	4.5	4.7	4.5
Tryptophan	1.1	1.1	1.0	1.0	0.9	0.9	1.0	0.8	1.0	0.4	1.0	0.4	1.0	0.9
Valine	5.6	5.4	5.5	5.1	5.3	5.8	5.4	5.9	5.4	5.1	5.5	5.2	5.6	5.7

available data on the distribution of vitamins in similar fresh and processed fishery materials have been tabulated together (Table IV). Though this method of reporting has the weakness that it relies in many instances on a comparison between the results of different investigators using different methods, and not strictly comparable fish samples, it is, for reasons noted above, the only obvious one available. From the data given in Table IV the following conclusions may be drawn.

The edible muscle portion of fish contains very little vitamin A. This vitamin does not appear to be appreciably destroyed by canning or smoking (Junker, 1956), but is apparently partially destroyed in the preparation of dehydrated fish. Fish which have a comparatively high oil content are usually excellent sources of vitamin D and, since this vitamin is relatively heat-stable, the canning process, as might be expected, does not appear to destroy it.

One hundred grams of fresh fish would supply roughly 10% of the average daily human thiamine requirement, and freezing and smoke-curing procedures do not appear to have any appreciable effect on this vitamin. However, thiamine is known to be labile to heat, and from the few figures available it would appear that canning destroys a considerable portion of this vitamin. In this connection it is important to note that Lopez-Matas and Fellers (1948) reported that about 75% of the thiamine in swordfish was destroyed by heating 90 min. at 115°C., and that 100% was destroyed in 110 min. at 121°C.

One hundred grams of fresh fish supplies from 5 to 10% of the average human daily requirement of riboflavine and, in contrast to thiamine, there is no appreciable loss of this vitamin on canning. Also, freezing, smoke-curing, and dry salting occasion no apparent loss. Fish flesh is almost invariably an excellent source of niacin, for 100 g. supplies between half and all of the human daily requirement. Since this vitamin is comparatively heat-stable, canning and other processing methods do not appear to decrease the amount present in fish products.

The early investigations of Birch and György (1936) and Lunde and Kringstad (1938) indicated that fishery products, and more especially fish livers, were good sources of pyridoxine. In later work Lunde (1939) reported that fish products contained between 50 and 400 "rat units" of pyridoxine per 100 g. When crystalline pyridoxine was available, Henderson *et al.* (1941) carried out a number of assays to determine the content of this vitamin in fish. Frozen cod and salmon contained 0.34 and 0.59 mg. per 100 g. respectively. In 1946, Ives *et al.* assayed 10 samples of canned salmon and found that they contained between 0.07 and 0.26 mg. of pyridoxine per 100 g., with an average value of 0.13 mg. These values were much lower than those later reported by Neilands *et al.* in 1947 (0.39 to 0.50 with an average 0.45 mg. per 100 g.). This vitamin is considered relatively stable in canning procedures so that these differences may have been due to the assay methods employed or the fish themselves. The mean, minimum and maximum values for this vitamin in seven types of canned fish products were 0.13 and 0.52 mg. per 100 g. (Neilands *et al.*, 1947).

Sea foods are comparatively good sources of biotin and in this respect compare very favorably with meats. Cheldelin *et al.* (1942) recorded the following amounts in fresh sea foods: halibut, 0.008; salmon, 0.0053; and oysters 0.0087 mg. per 100 g. Later, Ives *et al.* (1946) reported that canned salmon contained from 0.0067 to 0.0152 (average 0.0098) and Neilands *et al.* (1947) reported that canned salmon contained from 0.011 to 0.019 (average 0.015) mg. of biotin per 100 g. Not all canned fish appear to be an equally good source of this vitamin. Atlantic mackerel and tuna species averaged only 0.003 to 0.004 mg. per 100 g., while Pacific sardines and mackerel had from 0.018 to 0.027 mg. per 100 g. according to Neilands *et al.* (1947). The results obtained with salmon indicated that biotin in fish flesh is not affected by canning. Lopez-Matas and Fellers (1948) found that dehydration of swordfish destroyed most of the biotin. They also noted that the method of extraction of biotin from fish muscles is important since extremely high values were found for acid-extracted frozen and canned material.

Waisman *et al.* (1942) reported that commercial canning destroys from 30 to 40% of the pantothenic acid in flesh foods. They stated that the content of this vitamin in fresh salmon and cod flesh was 1.8 and 0.4 mg. per 100 g. respectively. Hoogland (1953) determined the pantothenic acid content of a variety of samples of fresh, frozen, smoked, and cold-stored cod and haddock fillets. He reported for the cod samples an average of 0.161, and for the haddock samples an average of 0.109, mg. of pantothenic acid per 100 g., and that the processing methods had no appreciable effect on this vitamin. These values were lower than those earlier reported by Waisman *et al.* for salmon (1942). Neilands *et al.* (1947) found that canned salmon contained an average of 0.58 mg. of pantothenic acid per 100 g. This value was similar to the earlier value of 0.7 mg. per 100 g. reported by Jukes (1941) for canned salmon. Average values of 0.17 to 0.57, 0.26 to 0.39, and 0.31 to 0.60 mg. of pantothenic acid per 100 g. of canned fish have been reported by Thompson *et al.* (1944), Ives *et al.* (1945), and Neilands *et al.* (1947), respectively. Cheldelin *et al.* (1943) observed no loss of this vitamin in simple cooking of fish.

There have been a limited number of studies concerning the amount of pteroylglutamic acid (PGA) in fish materials. Cheldelin *et al.* (1943)

TABLE IV
VITAMIN CONTENT OF RAW AND PROCESSED FISH PRODUCTS AS DETERMINED BY DIFFERENT INVESTIGATORS[a]
IV A. Vitamin A (mg./100 g. = U.S.P. units per 100 g./3333)

Fish	Raw	Canned	Smoked
Pacific salmon			
Sockeye	0.024 (3)	0.015–0.054 (12) (0.029)	
Pink	0.014 (3)	0.015–0.023 (12) (0.019)	
Chum	0.005 (3)		
Spring	0.078 (3)		
Pacific salmon (species not recorded)	—	0.017–0.097 (11) (0.036)	
Pacific herring	0 (3)		
Atlantic mackerel	0.045 (15)	0.065–0.274 (11) (0.130)	0.07 (14)
Atlantic herring	0.006–0.114 (15) 0.06 (15)	0.043–0.118 (11) (0.067)	0.05 (14)
	0–1.0 (31)	0.021–0.123 (12) (0.069)	
Atlantic herring (whole fish)	13.0 (31)		
Pacific mackerel		< 0.008 (11)	
Pacific sardines	0 (3)	0.021–0.123 (12) (0.069)	
		< 0.008 (11)	
Tuna sp.		< 0.008 (11)	

[a] Numbers 1–35 in parentheses indicate references given at end of table.

Table IV (*continued*)

Fish	Raw	Canned
Swordfish	0.48 (19) (frozen)	0.014–0.023 (12) (0.0175)
	0.29 (19) (dehydrated)	0.50 (19)
	IV B. Vitamin D (I.U./100 g.)	
Pacific salmon		
Sockeye	540 (3)	370 (2)
Coho	240 (3)	
Pink	540 (3)	193 (2)
Chum	300 (3)	
Spring	455 (3)	
Pacific salmon (species not recorded)	200–800 (16)	190–800 (5) (460)
Atlantic cod	0 (16)	500–500+ (11)
Atlantic mackerel	1100 (1)	500 (11)
Atlantic sardines	700 (17)	208 (flesh) (6) 608 (liquor + oil)
Atlantic herring	300–1700 (18)	333–500 (11)
Pacific herring	330 (assuming 10% oil content) (18)	333 (11)
Pacific mackerel		250 (11)
Pacific sardines	810 (3)	333 (11)
Tuna sp.	430–1, 570 (1)	100–333 (11)
Cod liver	6000 (10)	6000 (10)
Cod roe	65–85 (10)	80 (10)
Sild sardines (some canned 7–9 years)		290–1000 (1) (600)

TABLE IV (*continued*)
IV C. Riboflavine (mg./100 g.)

Fish	Raw	Canned
Pacific salmon		
Sockeye	0.04–.09 (21) (0.072)	
Coho	0.09–.123 (21) (0.109)	
Pink	0.036–.068 (21) (0.046)	
Chum	0.048–.072 (21) (0.059)	
Spring	0.152–0.256 (21) (0.231)	
Pacific salmon (species not recorded)	0.146 (22) 0.117–0.235 (24) (one very high value omitted)	0.195–0.250 (23) 0.14–0.17 (13) (0.16) 0.11–0.20 (12) (0.16)
Atlantic salmon	0.06 (7)	

	Fresh or Frozen	Salted	Kippered	Canned
Atlantic herring	0.025–0.150 (7) 0.27 (4) 0.32–0.34 (32)	0.19 (7)	0.31 (7) 0.45 0.30 (16)	0.17–0.20 (7) 0.16–0.23 (11) (0.19)

	Fresh	Frozen	Dry salted	Canned	Smoked
Atlantic haddock	0.014–0.019 (8) (0.017)	0.1 (7)	0.037 (7)	0.075 (7)	
Atlantic cod	0.019–0.025 (8) (0.023)	0.1(7) 0.013–0.026 (8) (0.018)	0.037 (7)	0.075 (7)	0.024–0.040 (8) (0.034)

TABLE IV (*continued*)

Food	Raw	Frozen	Smoked	Canned
Haddock	0.055–0.105 (7)		0.055–0.103 (7)	0.035–0.116 (7)
	0.014–0.019 (8) (0.017)	0.014–0.025 (8) (0.019)	0.017–0.037 (8) (0.024)	
Atlantic halibut	0.055–0.068 (7)	0.08 (7)	0.14 (7) (salted 8 days)	
Pacific halibut	0.10 (22)			
Atlantic mackerel	0.28 (7)			0.21–0.27 (7)
	0.35–0.36 (32) (0.36)			0.13–0.29 (13) (0.22)
				0.17–0.26 (11) (0.20)
Atlantic mackerel (whole fish)	0.43–0.64 (32) (0.57)			
Pacific sardines				0.12–0.23 (13) (0.18)
				0.29–0.38 (11) (0.33)
Tuna	0.10–0.11 (31) (0.10)			0.09–0.15 (11) (0.11)
Pacific mackerel				0.29–0.38 (11) (0.33)
Swordfish	0.049 (19)	0.092 (19) (dehydrated)		0.047 (19)
Lobster	0.055 (7)			0.058–0.075 (7)
Mussels	0.175 (7)			0.115–0.138 (7)
Clams	0.095 (7)			0.092–0.098 (7)
Atlantic oysters	0.06–0.35 (34)	0.21–0.26 (34)		
Atlantic shrimp	0.035–0.043 (35)	0.033–0.033 (35)	(11 days in ice)	

TABLE IV (*continued*)

IV D. Thiamine (mg./100 g.)

Fish	Raw	Canned
Pacific salmon		
Sockeye	0.125–0.135 (28) 0.14–0.155 (20) (0.148)	
Pink	0.139–0.150 (20) (0.143)	0.025 (28)
Coho	0.084–0.090 (20) (0.087)	
Spring	0.092–0.109 (20) (0.101)	
Chum	0.073–0.084 (20) (0.080)	
Pacific salmon (species not recorded)		0.018–0.052 (11) (0.030) 0.014–0.038 (9) (0.021)
Atlantic mackerel	0.17–0.20 (28)	0.021–0.045 (9) (0.034) 0.040–0.086 (11) (0.058)
Atlantic herring	0.024–0.06 (15)	0.043–0.118 (11) (0.067) 0.021–0.123 (12) (0.069)
Atlantic tuna	0.168–0.234 (31) (0.21)	
Atlantic shrimp	0.026–0.051 (35) (fresh) 0.018–0.045 (35) (11 days in ice)	

Table IV (*continued*)

Fish	Raw	Frozen	Canned	Dehydrated	Smoked
Pacific herring	0.011–0.040 (20) (0.023)				
Swordfish	0.053 (19)		0.013 (19)	0.026	
Atlantic cod	0.015–0.098 (8) (0.049)	0.04–0.078 (8) (0.057)			0.038–0.080 (8) (0.056)
	0.04–0.05 (28)				
Haddock	0.03–0.05 (8) (0.039)	0.017–0.064 (8) (0.043)			0.047–0.10 (8) (0.063)
	0.1 (28)				
Blue crab	0.075 (28)		0 (28)		
Oysters (various species)	0.098–0.180 (28)				
	0.08–0.18 (33)	Whole: 24% loss (33)			
	0.07–0.29 (34)	Ground: 63–67% loss (33)			
Freshwater fish (30)					
Lake herring	0.027–0.126	Slight losses (30)			
Suckers	0.0–0.04				
Carp	0.0–0.05				
Burbot	0.378–0.433				
Smelts	0.05				

TABLE IV (*continued*)

IV E. Niacin (mg./100 g.)

Fish	Raw	Smoked	Dehydrated	Canned
Pacific salmon	6.0–6.96 (22)			5.95–8.91 (9)
(species not recorded)	8.4 (15)			(7.81)
	5.5–6.7 (24)			6.2–8.1 (11)
	6.0–8.4 (26)			(7.4)
Swordfish	9.1 (19)		7.1 (19)	
Atlantic herring	2.9–4.0 (19)	3.4 (19)		
	2.9–4.0 (26)	3.4 (26)		3.8–5.9 (11)
	6.0 (29)			(4.8)
	3.7–4.1 (32)			2.9–3.35 (26)
Atlantic mackerel	5.5–7.9 (19)			4.01–11.4 (9)
	5.5–7.2 (26)			(7.82)
	9.4–9.3 (32)			5.0–6.6 (11)
	(9.35)			(5.8)
Pacific mackerel				8.0–9.4 (11)
				(8.7)
Pacific sardines				2.92–7.15 (9)
				(5.57)
				5.4–6.4 (11)
				(5.8)
Tuna	6.23–10.70 (31)			7.6–13.0 (9)
	(8.44)			(10.2)
				10.2–15.5 (11)
				(13.5)

TABLE IV (*continued*)

Fish	Raw	Frozen	Smoked	Canned
Shrimp	4.45–5.30 (35)	No decrease in 90 days (35)		0.78 (27)
				1.1–3.4 (9) (2.23)
Atlantic cod	2.3–3.3 (8) (2.57)	1.4–3.6 (8) (2.32)	2.1–3.5 (8) (2.93)	1.7 (26)
	1.7–3.0 (15)			
	1.7–3.0 (26)			
Haddock	3.2–4.3 (8) (3.72)	2.8–3.9 (8) (3.46)	3.9–5.2 (8) (4.56)	
	0.9 (25)			
Atlantic oysters	1.3 (26)			0.66 (27)
	1.41–2.52 (33)			1.08 (27)
	1.36–3.88 (34)	1.69–1.75 (34)		
Fresh-water fish (29)				
Lake herring	2.14–5.52			
	2.67		2.42	
Suckers	1.12–1.27			
	1.29		1.01	
	1.13		1.68	
Carp	1.33–1.55			
Burbot	1.64			

found that frozen salmon and cod contained 0.053 to 0.10 mg. per 100 g., and that relatively short cooking processes destroyed 46–74% of the vitamin. Ives *et al.* (1946) obtained different results depending on the microbiological assay method used for determining PGA (folic acid complex) in canned salmon. They used two methods and found relatively low concentrations ranging from 0.0001 to 0.0044 mg. per 100 g. with one method, and from 0.0053 to 0.0102 with the other. Canning practically destroys PGA. Thus, Neilands *et al.* (1947) obtained minimum and maximum values of only 0.0005 to 0.0022 mg. per 100 g. for seven types of canned fish analyzed. PGA is very readily destroyed in heating dry fish meals (Tarr *et al.*, 1954).

Vitamins of the B_{12} complex (cobalamins) are widely distributed in fish products, and more especially in the internal organs such as kidneys and liver (Tarr *et al.*, 1950; Southcott and Tarr, 1953; Karrick, 1955). The muscle tissue of white-fleshed fish is usually a comparatively poor source of this vitamin (Hoogland, 1953). Vitamin B_{12} is reasonably stable when autoclaved in faintly acid medium and therefore destruction during normal fish-canning procedures would not be expected. Indeed, vitamin B_{12} has been found to be comparatively stable in heated fish meals, unless the heating is continued for a considerable time at an excessively high temperature (Southcott and Tarr, 1953). Vitamin B_{12} is stable in frozen and smoked fish (Hoogland, 1953).

The tocopherols of fish flesh occur largely as vitamin E (α-tocopherol) (Harris *et al.*, 1950). Fish muscle tissue appears to have a variable vita-

References—Table IV

1. Aschehoug *et al.* (1939)
2. Bailey (1936)
3. Bailey (1952)
4. Klungsøyr and Boge (1953)
5. Devaney and Putney (1935)
6. Herraiz and Musmanno (1947)
7. Hoar and Barberie (1945)
8. Hoogland (1953)
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12. Pressley *et al.* (1944)
13. Thompson *et al.* (1944)
14. Willstaedt and Jensen (1937)
15. Cited by Lovern (1943)
16. Lunde (1939)
17. Cited by Grangaud (1950)
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19. Lopez-Matas and Fellers (1948)
20. Sautier (1946a)
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22. Cheldelin *et al.* (1943)
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28. Goldbeck (1947)
29. Klocke *et al.* (1946)
30. Klocke *et al.* (1947)
31. Braekkan *et al.* (1955)
32. Braekkan and Probst (1953)
33. Wentworth and Lewis (1958)
34. Fieger (1957)
35. Novak *et al.* (1956)

min E content as the following figures (milligrams per 100 g.) indicate: sardines, 4.5; salmon, 1.6; mackerel, 1.8; herring, 0.5 (Jansen and Kringstad, 1942); Baltic herring, 0.105 (Lücke and Willstädt, 1945) and haddock, 0.35 (Harris *et al.*, 1950). This variability is supported by the recent work of Einset *et al.* (1957), who found from 2.7 to 62.8 mg. of vitamin E per 100 g. of oil extracted from the flesh of different species of fish. Fish liver has been reported to contain 0.18 mg. per 100 g. (Lücke and Willstädt, 1945) and cod roe between 5.25 and 7.6 mg. per 100 g. (Kringstad and Folkvard, 1949) of vitamin E. The last-named investigators found that the vitamin was not destroyed during canning of cod roe. There is little doubt that vitamin E would be destroyed progressively in frozen fish in which storage conditions promote development of oxidative rancidity, though no published data regarding such destruction appear to be available. It is well known that vitamin E is quite rapidly destroyed in frozen tissues (Chipault *et al.*, 1945; Quaife and Dju, 1949). The probable role of the vitamin as a natural antioxidant in fish tissues has been emphasized by Einset *et al.* (1957).

The early information concerning the distribution of ascorbic acid (vitamin C) in fish materials was reviewed by Lovern (1943). These early reports were confusing, but in general the reliable work indicated that fish flesh contained little of the vitamin. During a study which involved recovery of added ascorbic acid to Pacific salmon muscle it was found that small amounts of reducing substances equivalent to about 2.5 mg. per 100 g. of ascorbic acid were present (Tarr, 1948). Hastings and Spencer (1952) found that edible marine products contained both free and bound ascorbic acid, there being a significant amount in tuna liver, salmon roe, herring roe, and oysters. Fresh salmon muscle was reported to contain 1.3 mg. per 100 g. Severe destruction of the ascorbic acid was reported following canning of herring roe and muscle by the above investigators. However, they observed no appreciable destruction of the vitamin in the canning of tuna and oysters, a result which has as yet not been satisfactorily explained. Kringstad and Folkvard (1949) reported relatively high levels of ascorbic acid in cod roe (about 50 mg. per 100 g.), but they did not determine the amount of destruction due to canning. Separation and identification of ascorbic acid by chromatographic techniques does not appear to have been attempted.

Though there must be a considerable loss of vitamins in the aqueous and oily liquids which exude from fish during precooking procedures (for example, in tuna canning), in the drip which exudes from defrosted fish, and in liquors which are discarded from canned fish, there does not appear to be much information in the literature concerning the magnitude of these losses. Junker (1956) stated that the approximate 10% loss of vitamin A which occurred on cooking fish was due to physical loss in the exudate. It would be interesting if more information concerning them could be accumulated.

C. EFFECT ON FATS AND MINERALS

Though there is now fairly abundant information in the literature concerning the distribution, types, and amounts of triglycerides and phospholipids in fish flesh, there does not appear to be much information concerning the effects of processing on their nutritive value. As pointed out previously, the hydroperoxides which form during oxidation of the unsaturated fatty acids of fish oils undoubtedly occasion loss of essential factors such as vitamin A, and this destructive effect may be carried over to the essential factors which are normally included in a given ration. Biely *et al.* (1955) were unable to detect any difference in the nutritive value of herring meals which were stored for one year at 20° or 37°C., even when these meals contained as much as 7.6% of fish fat. Common *et al.* (1957) have shown that quite severe heating conditions are required to render fish oils toxic. These studies would certainly indicate that normal processing procedures such as the canning of fish are highly unlikely to affect adversely the nutritive value of the oils. On the other hand, severe oxidative rancidity, such as undoubtedly occurs in many salted fish products, may well affect the digestibility of the fats. So far, however, the difficult problem of the study of the digestibility of these relatively highly oxidized fats does not appear to have been overcome.

Fish and shellfish are excellent sources of most of the mineral elements required by man, including iodine and fluorine (McCance and Shipp, 1933; Nilson and Coulson, 1939; Lee and Nilson, 1939). Losses of these mineral elements during processing is undoubtedly entirely physical, due to liquids discarded from fish products (McCance and Shipp, 1933). Canning would undoubtedly have no appreciable effect, and indeed, Jarvis *et al.* (1926) found no loss of iodine on canning Pacific salmon.

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CHAPTER 7

Fish in World Nutrition

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I. Background Information

A. Historical Data

A substantial part of the arable lands of the world has been brought under cultivation through man's quest for food to feed an ever increasing population. Forests have been leveled, swamps drained and deserts irrigated. Even soilless agriculture is being tried—though on a very limited scale. Concurrently, the fishing frontiers have been pushed farther out to sea from the immediate coastlines of all continents. Many species of fish are pursued over thousands of miles of ocean—throughout their range of distribution. In expanding these boundaries for fishery activities, species new to the fish markets have been found in abundance and have been utilized. Efforts are now being made to exploit the deeper waters of the oceans and thus to push outside of the continental shelves.

In the dawn of history the sea provided, primarily through molluscan shellfish, a readily available food source. Shells at ancient dwelling sites constitute indestructible evidence to late generations of this historical priority of aquatic foods. In the ancient world, fish gained in importance when the Mediterranean population pressure forced cereals on the scene as the bulk of food to take the place of the all-dominant meat from earlier epochs. Fish became the despised food of the poor in the form of mackerel, anchovy and tuna (as salted products) and as sand smelt (eaten fresh). The fish delicacies of the luscious Greek and Roman banquets belonged to a number of less common but highly praised fish, such as scarus, sturgeon, eel, sheatfish and pike. The Romans favored muraenas and mullets (see further Chapter 1 of this volume, and Cutting, 1955).

For several centuries, fishing and farming advanced at more or less comparable rates. In medieval times, the world saw the rise of the great herring and other fisheries in the Atlantic, off Western Europe, and a rapid increase in agricultural production in Central Europe. During the colonial period in North America, fishing and farming developed simultaneously and almost at the same rate. But in more recent times, especially since the middle of the nineteenth century, agriculture in North America has far outdistanced the fishing industry. In general, this has also been true throughout the rest of the world. As long as more land could be brought into production, less and less consideration was given to the sea as a source of food. Recently, however, this trend is being reversed. Most of the world's good soils are in use. Much topsoil has been allowed to blow and float away, or to be depleted through poor, or even too intensive, cultivation. Greater attention now has to be given, therefore, to exploring fishery resources and tapping their vast stores of animal protein food. If the present trend is maintained, the oceans will be combed for food fish as they were for whales in the first half of the nineteenth century.

The distribution of human population on earth was historically determined by climate, potential agricultural land, and channels of transportation, such as harbors, rivers, straits and overland roadways. Population became concentrated where these conditions were most favorable. Some of the major concentrations of fish are quite remote from dense human populations, e.g., the fringes of the Polar regions around Greenland and Alaska, the west coast of South America, Africa and many others. More than 90% of the world's catch originates in the Northern Hemisphere, yet the southern oceans constitute the greater part of the whole ocean and are known to encompass rich fishery resources. The high perishability of most seafoods further complicates problems of exploiting these distant resources, requiring special techniques for capture, preservation and transporting. This involves the operation of long-range expensive fishing expeditions, now undertaken by several nations, primarily the Soviet Union, Japan and the United States; in the latter case, for tuna, both to the Southeast Pacific and quite recently to the tropical Atlantic also.

The distant cod riches of Newfoundland were exploited early in human history, presumably as early as the fifteenth century by the Portuguese, and subsequently pursued also by the French, Spaniards and British. Today, most major West European countries, together with the Soviet Union, Poland, and East Germany, take part in the fishing off Newfoundland, Labrador, Iceland, and Greenland. Redfish (ocean perch), haddock and herring have been added to the list of catches in these areas.

Through the years a number of studies have been conducted to establish the importance of fishing to world nutrition (Taylor, 1932; Borgstrom, 1951; Galtsoff, 1952; Finn, 1954, 1960; Chapman, 1947; Vercelli, 1952; Jul, 1952; Weiss, 1953; Sandberg, 1945; Predel, 1957) or to elucidate some particular aspect of this multi-faceted field. Furthermore several books and reviews survey this vital area (Coker, 1947; Ommaney, 1949; Taylor, 1951; Popovici and Angelescu, 1954; Morgan, 1956; Dietrich and Kalle, 1957; Blanke, 1958; Walford, 1958).

B. Present Catch

1. *Marine and in General*

World War II caused a serious disturbance in world fisheries. The recovery was rapid, however, in Europe, Japan, and the U.S.S.R. In most countries bordering a marine area, chief emphasis was put on fishing as a means of rapidly acquiring badly needed high quality protein. A number of new fishing nations emerged and are already quite important in the world catch (see Volume I, Chapter 2 by Riedel). The Food and Agriculture Organization estimates the sea harvest in 1959 to be in excess of 35 million metric tons (see Table I). In addition approximately 4.3 million metric tons came from freshwater. Not all landed fish is for direct human consumption. Approximately one-fifth of the catch goes into the manufacture of oil and meal which reach the human consumer only indirectly in the form of oleomargarine or converted into animal food products. Furthermore one-tenth of the aquatic catch is comprised by shellfish. This leaves an amount of 28 million metric tons of food fish, 24 million tons of which refer to the seas and the remainder to freshwater areas (lakes, rivers, and ponds).

TABLE I
MAJOR CATEGORIES OF AQUATIC FOODS, 1959[a]

Fish	Million metric tons
Aquatic foods	
Herring, sardine, anchovy, etc.	8.98
Cod, hake, haddock, etc.	4.52
Fresh-water fish	4.30
Mullet, jack, sea bass, etc.	3.61
Tuna, bonito, mackerel, etc.	1.92
Flatfish (flounder, sole, halibut, etc.)	0.86
Salmon, trout, smelt, etc.	0.62
Nonidentified marine fish	6.76
Shellfish	
Mollusks	2.19
Crustaceans	0.79
Miscellaneous	
Algae	0.48
Other products	0.07
	35.33

[a] Source: Food and Agriculture Organization Fisheries Yearbook, 1960.

WORLD AQUATIC HARVEST

Year	Million metric tons	Year	Million metric tons
1850	1.5–2.0	1952	24
1900	4	1954	26.5
1920	9.5	1956	29.9
1938	20.5 (18)	1958	32.1
1948	19.5	1959	35.3
1950	23	1960	37.8

No other food commodity has shown an increase comparable to that of fish. Since the beginning of this century the total fish and shellfish catch has soared from a few million tons up to the present figure (see tabulation for data based on estimates of various workers, League of Nations, and FAO statistics). According to statistics of the Food and Agriculture Organization, 1935–1960, fish has the lead in the expansion of production volume among all foods, exceeded only by citrus fruits and sugar. No other animal products can contend for this top position held by fish (see Table II).

TABLE II
AQUATIC CATCH

	1938	1948	1951	1953	1954	1955	1956	1957	1958	1959	1960
Total[a]	20.5	19.1	27.0	27.1	27.0	28.4	29.9	30.8	32.1	35.3	39.0
Nonfood	2.6	2.5	5.0	5.8	4.6	4.6	5.1	5.0	5.2	7.0	8.8
Food	17.9	16.6	18.6	21.3	22.4	23.8	24.8	25.8	26.7	28.3	30.8
Fish	18.3	17.0	19.3	23.0	19.2	20.6	21.5	22.3	23.6	24.7	25.0
Shellfish[b]	1.7	1.9	2.2	3.4	2.7	2.7	2.8	2.9	2.8	3.0	3.1
Plants	0.5	0.2	0.3	0.7	0.5	0.5	0.5	0.6	0.5	0.6	0.6
Marine	18.6	17.3	24.1	24.1	24.2	25.4	26.8	27.3	28.3	31.0	34.5
Fresh-water	1.9	1.8	2.9	3.0	2.8	3.0	3.1	3.5	3.8	4.3	4.5

[a] Million metric tons live weight.

[b] Approximately 70% shell weight.

Owing to the improvement in fishing technique and, to a large extent, the renewal of the fishing fleet, the productional potential of world fishery must be considered good.

Nevertheless, the total annual value of the world's fish products is less than 1.5 billion dollars. This is less than the total value of poultry and eggs being produced in the United States. In addition, meal, oil, and other industrial products account for another 200 million dollars.

2. *Fresh-Water*

In many countries, fresh-water fisheries supply a substantial part of the nation's protein food. Almost half of the world's fresh-water catch, approximately 1.8 million metric tons, refers to China, where raising of fish has been traditionally predominant. Fish is taken from an area no less than 16.5 million hectares, of which 70 lakes (6,000–500,000 hectares) constitute 6.28 million hectares. Although reduced relatively in importance, the fresh-water catch still maintains its absolute size and is even expanding, chiefly by resorting to full-scale utilization of more distant lakes and rivers and the simultaneous build-up of processing and distribution facilities in an obvious effort to move from a local subsistence basis to procuring highly coveted animal protein for the millions in cities, for numerous industrial enterprises, and also for the communes. Thus, the well-known salt lake Koko-Nor on the high plateau of Chinghin is said to be circumscribed by a road along which fishing villages have been erected, together with processing and icing establishments, and equipped with modern fishing craft. Its catches have increased many times and are stated as reaching 45,000 metric tons a year (Denisov, 1961; Saburenkov, 1961).

The Soviet Union presumably ranks second. Its inland waters account for 1.2 million metric tons, but the Caspian and Black Seas, Lake Aral, and a few others are all salt-water bodies. The expanding irrigation, together with the effects of the rapid industrialization (pollution, ascending figures for water usage, hydroelectric plants), has drastically affected fresh-water fishing. Artificial waters (irrigation canals, reservoirs, dams, etc.) offer some compensations (see Volume I, Chapter 3). Official support to maintain village ponds and special fish-raising areas in cities constitute another major endeavor to hold the fresh-water front. Fishing from natural fishing waters is greatly supported by stocking with fingerlings and feed organisms, transplanting, and other production-increasing measures. Proportionately the greatest expansion is taking place in the large Siberian rivers, the mouth of the Ob, however, being the largest source. This vast body of water is already delivering more fish than the entire Arctic Sea waterfront.

The fresh-water fisheries of the African continent are concentrated chiefly in three areas: Lake Victoria, Lake Nyasa and adjacent areas, the Nile basin, and Congo basin. Tanganyika and Uganda together account for 100,000 metric tons. The Victoria waters are rich in fish. The major food catch consists of various *Tilapia*. Since time immemorial, they have been a great asset to the dense population living around these shores (Worthington, 1953; Hickling, 1961).

The Great Lakes provide the United States and Canada with about 50,000 tons of fish a year, but in comparison to the immensity of these waters, yields are low. In northern Europe and Asia likewise, fresh-water fisheries are of considerable importance, although everywhere hampered by population growth and industrialization. Both Japan and Western Europe are also suffering from the damaging effects of extending use of chemical sprays, acting as fish poisoning agents in many nations' waters.

Inland fisheries are important as a food resource in Argentina, Brazil, and Venezuela. The Amazon River contains many fresh-water species, among them the "pirarucu." This gigantic fish, which weighs up to

200 lb. and is found only in the Amazon, is dried and shipped all over Brazil as a substitute for cod. This river also teems with turtles, whose meat, fat, and eggs are consumed throughout the region. In most of Latin America, however, fresh-water fisheries are operated by fishermen owning no more than a small canoe and a few hooks and lines. Lack of capital blocks the introduction of modern equipment.

3. *Ponds and Fish Cultivation*

Fish are reared in ponds in many countries. The practice originated in 437 B.C. in China, where it also expanded into the rice paddy fields. On many Pacific islands, as well as in China, ponds near the sea or connected with it contain both fresh-water and salt-water species (see Volume I, Chapter 5 by Drews). The pond area of China is today 2.94 million hectares, of which approximately one-third are marine. Their average productivity is reported as 862 kg./hectare (Saburenkov, 1961).

Pond culture was introduced into central Europe during the fourteenth century, and later into the Balkans. In the European fish ponds, the principal species is the common carp; in Southeast Asia and Japan many other species are reared (see Volume I, Chapter 3 by Mann and Chapter 5 by Drews).

There are more than 2 million fish ponds in United States farms, chiefly in the southern states and largely built in the last 30 years. They have been built with multipurpose aims in view: as a reliable source of water for stock and irrigation, for conservation, for recreation—and not least, for fish raising (Compton, 1952). Initially, the farm pond evolved as a method of supplementing the daily food. Each acre of such water can be made to yield 150–450 lb. of pan-size fish each year. When well managed, they can support 400–600 lb. of fish. Fertilizing is required at regular intervals.

Recently attempts to produce river catfish (*Ictalurus* sp.) commercially in United States ponds have been initiated. The only food-fish culture enterprises in the United States are producers of rainbow trout (*Salmo irideus*)—see further Borgstrom (1961a). This fish is commercially produced and frequently in combination with freezing plants in Japan and Denmark. Most of their production enters international trade.

Rice-fish farming, patterned after Southeast Asia and with favorable results, is reported from Texas, Mississippi, Louisiana, and Arkansas, the latter being the major producing area. The principal species is the bigmouth buffalo fish, *Megastomatobus cyprinella*. This fish is preferred to carp by the United States public. Yields of more than 1,000 lb. per acre have been obtained in heavy delta soils; 500 lb. constitutes a good average when heavy stands of stubble have been left over from the preceding rice crop.

In the Far East, pond fish are raised in relatively small bodies of water; boglands, swamps, and ravines are utilized, as well as the waters of irrigation canals and reservoirs (Blanco and Villadolid, 1939). In many areas (China, Japan, Java, and others), fish are raised on flooded rice paddies. Annual yields of one or more tons to the acre are not infrequent.

Israel started fish farming before World War II and introduced the carp from Yugoslavia into its fish ponds. The average annual production is at present 6,000 metric tons. The availability of dependable water resources is hampering further expansion.

Twelve years ago various *Tilapia* were introduced into the lakes and rivers of Madagascar. Pond cultivation started in the central part of the island and the number of ponds in 1960 was given as no less than 80,000 (Anonymous, 1960a).

4. *Marine Cultivation*

Only through oyster farming is it possible nowadays to meet the United States' market demands. Due to excellent estuarine habitats, Louisiana produces more oysters than all other Gulf states combined.

Cultivation of other marine organisms in salt-water ponds is subject to trial at various places, both along the Pacific and in the Gulf area. A well-known center for experiments of this nature is Bears Bluff Laboratories, Wadmalow Island, South Carolina. The raising of shrimp has been practiced in the Orient for five centuries or more. Ample tidal marshes exist along the South Atlantic and Gulf coasts where such ponds could readily be built. The question is whether such cultivation can successfully compete with trawling.

A modern, seagoing shrimp trawler costs between $20,000 and $40,000. Shrimp ponds can be built for $250 to $600 an acre. Such a trawler can catch annually 20,000 to 50,000 lb. of shrimp. In India 350 to 1,000 lb. of shrimp are produced per acre of pond during a five-month season. Calculating these figures and, if the United States marshlands could produce shrimp at the same rate, the equivalent cost of a shrimp boat would yield annually between 12,000 and 160,000 lb. of shrimp.

Efforts are also under way to raise in cultivating ponds a large-size fresh-water shrimp, found in rivers and canals of Florida. A related species is widely eaten in Cuba, where they are called little lobsters. Some difficulties are encountered in the continuous reproduction in captivity. Species of smaller type, found in great numbers in the Mississippi and the Ohio rivers, are also tried for cultivating purposes.

5. *Whaling*

Although not fish, whales merit attention in a study of this nature. Being so close to the primary photosynthetic production—with only two conversion chains—they belong to the most efficient convertors, in general, and of the planktonic riches of the Antarctic, in particular. The suckling baby blue whale for two years grows approximately 150–200 lb. per day, the standard weight of a man. It is estimated that the mother consumes per day 2 metric tons of "krill" (a zooplancter belonging to the euphasids).

International control of the annual catch of whales has only been partially successful. At present the International Whaling Commission no longer functions, as two members have withdrawn. Germany has resumed whaling. Japan and the Soviet Union have both expanded their operations appreciably. No less than three newly built modern whaling factories (147,000 gross tons) have been added to the Soviet fleet in the period 1959-61. Norway is at present (1961) in the process of selling its major factory whalers to Japan.

Whaling is almost entirely concentrated in the Southern Hemisphere, since the chief stock outside Greenland is almost depleted. A few whales are caught off the Canadian Pacific Coast. Presumably, there are potential possibilities of larger catches in this region. New whaling districts are centered around Cook Strait in New Zealand and off Durban in South Africa.

A new development is the utilization of whales for the production of fresh meat—chilled, canned, or frozen. Japan, the Soviet Union, Norway, and the United Kingdom are utilizing whale flesh for human consumption. Only a fraction of the potential amount of flesh available in whales is used. Estimates of the total of this has varied between 325,000 and 2 million metric tons, due to the possibility of using meat from all whales and the availability of facilities to save, handle, and transport the flesh. Furthermore, seasonally the meat is so rancid that only extensive oil removal can make it edible for human beings. At any rate, 100,000 metric tons of whale meat is equivalent to the yield of 570,000 full-grown steers.

Whales are hunted especially for their oil. Oil-extraction methods have improved, thus substantially increasing the oil output per animal unit as much as 50–80%. This oil constitutes one-tenth of the world's consumption of animal fats (Kondrup, 1952).

Meal is also manufactured on the factory ships and in on-shore stations (82,000 metric tons in 1955-56). Nevertheless, large quantities of offal are still thrown back into the sea as waste products.

The shortage of horse meat for mink food is making whale meat and meal of other mammalians (sea lions off Alaska) attractive. A revival of

East Pacific shore whaling took place in 1957 and is expanding. So is the whaling station near Paitu, Peru, now served by three killer vessels, secured from Europe. Currently the fur breeders of the Pacific Northwest, especially the mink ranchers, use more than one million pounds of whale meat imported from Canada or Japan. The whale meat is, however, not as dependable for animal feeding in general as fish meal; see further Chapter 2, Part I, of this volume.

6. *Miscellaneous*

The *dugong* (sea cow or sea pig) has a flesh similar to that of pork and is greatly relished by the coastal population where it abounds. It is an inhabitant in restricted areas in the Indo-Pacific from the Red Sea and east coast of Africa in the west to the Solomon, Marshall, and New Caledonia islands in the east (Jones, 1959).

The *manatee* (sea lion) feeds on the subterranean pastures of algae and grass. It is a food highly esteemed by many peoples in tropical America, including the Caribbean. To this category of grazing animals belong several turtles, the most famous of which is the green turtle of the Caribbean, which once astounded Columbus by its immense numbers. As a food source, they paralleled the role of the prairie bison to North America (Carr, 1956). In many tropical areas—India, Indonesia, and Ceylon—turtles still provide supplemental protein, although they have been severely decimated in most regions.

C. Yields

It is interesting to note that yields obtainable from catches through recent years give an indication in broad terms of the productive capacity of various waters, as influenced by latitude, climate, availability of nutrients, etc. Largely they follow the findings of studies on primary production and benthos accumulation. Certain basic characteristics are obvious. The Baltic and the Mediterranean show low productivity, for different reasons. Temperate latitudes deliver more fish, and Arctic regions are sparse. Fresh waters are more readily fertilized than marine areas, and peaks in production are reached in controlled ponds. These latter come into the producing range of farm animals (Table III). There is still a great deal of argument as to the true potential of tropical waters (see further Steemann-Nielsen, 1960).

D. Subsistence Fishing

What now has been depicted is the situation as it can be analyzed from available statistics. In many countries, fresh-water fish is not listed in the commercial statistics. Thus, it is known that families inland in the

TABLE III
PRODUCTIVE CAPACITY OF SEA AND LAND

Fish catch of selected sea areas[a]		Fish yield of land water area[b]		Land animal yield	
Sea	kg./hectare	Water area	Live weight, kg./hectare	Flesh	Live weight, kg./hectare
Sea of Azov	80	Oligotrophic lakes (temperate)	1.2–6.5	Cattle	84
East China Sea	55	Entrophic lakes (temperate)	21–200	Hog	500
Japanese Sea	29	Atlantic off Iceland	34.0	Beef cattle (pastures)	5–250
North Sea	24–35	Fish ponds, unfertilized	25–125		
Caspian Sea	12	Fish ponds, brackish	—		
Baltic Sea	4–6	Fish ponds, tropics	300–1200		
Barents Sea	4.5	Fish ponds, fertilized	200–9000		
Mediterranean	1.5	Tropical lakes	2000		
White Sea	1.2				

[a] Source: Cherfas, 1952.

[b] Source: Kalle, 1948; Mortimer and Hickling, 1954.

north of Sweden consume from local sources up to 100 kg. of fish per capita. The Lake Titicaca provides food for the adjacent indigenous populations of the Andes. Indirect evidence in dietary surveys show that individual fishing plays a major role in the United States (Borgstrom, 1961a).

According to Wilcox (1947), Thailand is the rice country of a "vast agricultural Venice. . . . It is a combination rice empire and fish pond. Fish go a long way in supplementing a rice diet." Family subsistence is, in effect, taken from every stream, canal, lake, and swamp. Artificial fish ponds are common throughout the Bangkok region, with well-established rules for emptying the ponds.

In other words, it is most likely that large quantities of fish are caught for self-sustenance, the consumption of which never is registered. Recent surveys from Southeast Asia also confirms this. In these cases, the population depend largely on fish for their daily protein need, as other meat is not available.

Dietary surveys clearly show that in Africa the best-nourished peoples are frequently those living close to lakes and rivers and consuming the fish they themselves catch (Nicol, 1952; Hickling, 1961; Borgstrom, 1962b).

In some cases, the Food and Agriculture Organization has made an effort here to include estimates of such noncommercial catches, e.g., in the Philippines (60%) and Malaya (11.5%). The figures in parentheses indicate the percentage of the national catch attributed to such subsistence fishing.

These factors must be borne in mind particularly when analyzing the future prospects for expanded fish consumption. In other words, the fish resources of the world have already been tapped for food purposes to a greater extent than available statistics might indicate.

E. Utilization

1. *General*

About two-thirds of the world's catch is used directly as human food in various forms—fresh, frozen, canned, or otherwise preserved. The remainder is reduced to oil and meal. In both cases these items contribute an additional amount of food to the human household. Whale and menhaden oils are raw products important to the oleomargarine industry of Europe and the Soviet Union.

National preferences and the final destination of the catch—whether for domestic consumption or for export—largely determine the form in which fish is marketed. In the United States, almost equal amounts of fresh and canned fish are sold. Frozen fish is capturing more and more of the market, and about a fourth of the catch is reduced to oil and meal. In contrast, the United Kingdom, with an annual catch half that of the United States, markets more fresh and frozen fish (850,000 tons as against 730,000 tons for the United States) but uses only small quantities for canning. In no country does the share of canned fish in the total catch even approach that of the United States. A clear distinction should, however, be made between the relative standing of each type of fish product and its absolute volume. This point will be further elucidated in Chapter 19, constituting a comprehensive review of present general trends in fish utilization.

2. *Fish Meal*

Certain species of nonedible fish and the waste from processing the edible kinds are reduced to meal and oil. Fish meal is increasingly used for feed, as the value of its high-quality concentrated protein has been recognized. The waste of fish species that contain little oil in their bodies, such as cod, haddock, and redfish, is converted into fish solubles, a kind of liquid protein. When fish is reduced to oil, the water remaining after the separation of the oil still contains some portions of fish and various minerals. The solids are screened and added to the meal. The water, known as stickwater, was formerly discarded, through ignorance of its value for feed. Years of research and experimentation have resulted in the development of processes for concentrating stickwater into a product with high vitamin B content—fish solubles (see Chapter 9). This product is greatly valued for inclusion in mixed feed and is considered to be a special factor in animal growth. Peru, the United States, and Norway are the chief producers of fish meal, followed by the United Kingdom, Japan, and Canada.

Meat meals from slaughterhouse waste have generally been found inferior to fish meals. Whale meal is becoming a good substitute for fish meal, but is more deficient in minerals and to some extent in B vitamins.

3. *Fish Oils*

Fish oils are interchangeable to some extent with vegetable oils. Fish-liver oils have been employed for medicinal purposes for centuries; they were prescribed for rickets in the Middle Ages. The discovery of their vitamin content has led to their use in vitamin oils and concentrates.

The world's output of fish oils averaged 350,000 metric tons a year during 1955-1959, 24% above the level of the nineteen-thirties. The United States leads in production, followed by Norway and Japan, in that order. During World War II, the annual output of the United States declined about 25%, and that of Japan and Norway fell catastrophically. In the United Kingdom, the fishing fleet was requisitioned for military purposes, and production of fish oil ceased altogether. Only Iceland is producing more fish oil than prior to the war.

The Marfleet refinery (United Kingdom) serves the 400 trawlers operating from Hull and Grimsby, equipped for preliminary oil rendering at sea. In this plant, 40% of the world's annual supply of liver oil (30–35,000 tons) is manufactured, basically from 100 million codfish livers (Anonymous, 1961d).

The fish-liver oil industry is increasingly affected by the competition from synthetic vitamin A produced from ionone, coriander seed oil, etc. Fisheries used to hold a monopoly in this field. Leading producers, chiefly of cod-liver oils, are the Soviet Union, followed by Norway (second), the United Kingdom (third), Iceland (fourth), and Japan (fifth). This declining trend has led to the development of a canned-liver industry in the Soviet Union and Japan, as well as the use of liver in porks, sausages, etc. Norway benefits from the fact that its fishing industry is carried on close to the coast at low temperatures that make it possible to process millions of fish livers in the shortest possible time.

F. INTERNATIONAL TRADE

1. *General*

When discussing the position of fish in world nutrition, its part of the international trade must not be overlooked. What is caught in the Northern Hemisphere is only partly consumed there. The bacalão is especially cherished in the tropics of Latin America and Africa. Salted, dried cod was always considered an important part of their protein diet for several centuries, along with other fish prepared in a similar way. As a whole, cured fish has long held an established place in the diet of these regions. In Jamaica, e.g., dried salted cod provided the chief source of animal protein for the poorer sections of the population. Cured cod is also a staple item in the diet of the Brazilian population, on the average 60% of the fish protein intake (Borgstrom, 1958).

2. *Fish and Milk Contending*

Even when it comes to the international food trade, fish plays a proportionately greater role among the less-well-fed nations of the world than do other major food commodities. Table IVa lists the approximate amount of fish and milk protein that reaches the underfed countries of the world. As a provider of cheap animal protein, dried fish still holds the key position it has maintained through the centuries. In spite of the

TABLE IVa
FISH AND DAIRY PRODUCTS IN WORLD TRADE, 1958-1959 (1,000 METRIC TONS)

Fish and dairy products	Total amount	Sold to				Sold to underfed countries	Protein (%)	Available protein
		West Europe[a]	United States	Soviet Union	Total			
Fresh and frozen	868	330.7	261.5	54.8	647.0	223.0	10	22.3
Tuna	130	—	80.0	—	80.0	50.0	15	7.5
Cured								
Stockfish	44.5	1.0	—	—	—	43.5	80	34.8
Salted cod								
Wet	45.0	—	9.8	—	—	35.2	20	7.0
Dried	103.5	—	—	—	—	103.5	70	72.5
Dried herring	5.8	—	—	—	—	5.8	50	2.9
Salted herring	167.8	42.3	5.0	53.2	101.1	66.7	20	13.3
Miscellaneous dried and salted	103.2	—	—	—	—	99.0	—	49.5
Smoked	14.5	1.4	1.9	—	3.1	11.9	30	3.4
								182.7
Condensed whole milk	500	38	7	—	39.0	461	8	36.9
Dehydrated milk	385	153.5	4	—	157.5	231.5	35	81.0
Cheese	481	323	29.5	—	352.5	128.5	25	32.1
								150.0

[a] Scandinavia, United Kingdom, France, Holland, Belgium, and West Germany.

extensive nature of various international programs using dehydrated milk, fish on the average still surpasses milk on the world market with regard to the total amount of protein. In isolated years, when relief deliveries are expanded, milk may exceed fish. In spite of the world production of milk being 2.5 times larger than that of fish, these two items are equally important to world feeding in supplementing the low protein diets of critical areas (see also Section IV, C).

3. *Fish Proportionately a Leader*

There is another way of gauging on a relative basis this effectiveness of world animal protein in terms of major commodities. Employing the figures indicating the proportionate share of major animal protein in the world's total population, the number of human beings who theoretically could be fed by each protein category can be calculated. In other words, this would be the number of individuals who would be provided with animal protein from each major source if these available protein sources were equally divided. By analyzing, insofar as available statistics allow, the actual consumption in individual countries the actual present disposition of these proteins can be calculated in an approximate way (see line II in Table IVb; see also Borgstrom, 1962b).

TABLE IVb

DISTRIBUTION OF MAJOR ANIMAL PROTEINS

	Milk	Meat	Fish	Eggs	Poultry	Total
Million tons	10.5	8.4	3.1	1.4	1.0	24.4
Percentage	43.4	34.6	12.2	5.7	4.1	100
I. Human population	1,302	1,038	366	185	123	3,000
II. Actual number provided[a]	1,174	720	670	—	—	2,564
III. Ratio (II/I)	0.9	0.7	1.8	—	—	—
IV. Deficit (or excess) millions fed	—128	—318	+304	—	—	—

[a] Calculated on the basis of each individual country.

The discrepancies between these two sets of figures (lines I and II) clearly reveal that the overwhelming percentage of milk and meat is being consumed by a minority of the world's peoples and largely those that are favored with rich soil and water resources. More important in this context is the outstanding fact that fish constitutes the animal protein source of a much wider proportion of the world's total population. When analyzed in terms of distribution, the sphere of influence of both milk and meat shrinks, while that of fish greatly expands—almost twice what sheer quantity would lead one to anticipate.

G. Nutritional Role

The biological or nutritional quality of the protein contained in various species and types of fish and shellfish compares very favorably with that of muscle meats of beef, veal, pork, lamb, mutton, and poultry (see further Chapter 2, Parts I and II, this volume). The relative content of essential amino acids is almost identical. A special advantage is the high degree of digestibility. In general lysine, methionine, and tryptophan are the three essential amino acids, deficiencies of which are frequently encountered in plant protein. Fish protein provides all these vital constituents.

This is the over-all picture, which clearly points toward the potentialities for increased use of fish. When analyzed further, the position of fish products is in reality even more significant than these actual figures reveal.

Fish maintains a unique position as a protein source, being the most potent in this respect whether the protein content is calculated on the basis of 100 calories (Table V) or merely in relation to total dry matter (Table VI). Even fatty fishes compare favorably with defatted milk powder, where lactose constitutes a filling bulk. For other factors influencing the protein content, see Chapter 2, Parts I and II. Small-sized fish generally carry less protein in relative weight than do large

TABLE V

GRAMS OF PROTEIN IN 100 CALORIES OF SELECTED FOODS[a]

Food	g./100 cal.	Food	g./100 cal.
Manioc (cassava)	0.8	Cow's milk (3.5% fat)	5.4
Banana	1.0	Eggs	7.9
Sweet potato (*Ipomoea batata*)	1.1	Beef (lean)	9.6
Rice (white, milled)	1.7	Skim milk	10.0
Taro	1.7	Nonfat milk solids	11.3
Millet (*Eleusine* sp.)	2.0	Fish, fatty	10.2–13.2
Maize (whole-meal)	2.6	Fish, lean	15.0–21.0
Millet (*Setaria* sp.)	2.9	Fish, dried (cod)	21.8
Sorghum	2.9	Fish flour (extract)	22.0–23.0
Wheat flour (medium extract)	3.3		
Millet (*Pennisetum* sp.)	3.4		
Groundnut (peanut)	4.7		
Bean or pea	6.4		
Soybean	11.3		

[a] Calculated by the author from standard reference books on food composition.

TABLE VI

PERCENTAGE OF PROTEIN OF DRY MATTER IN MAJOR FOODS[a]

Animal foods	%	Vegetable foods	%
Cod	92	Manioc (cassava)	1.5
Herring	81	Millets	3–4
Beef	75–80	Rice	5–6
Salmon	72	Corn	7–8
Eggs (liquid)	50	Wheat	9–12
Nonfat milk	50	Potato	12
Pork	50	Beans	25–35
Milk	35	Leaf protein	40
		Sunflower seed	50
		Soybean flour	55

[a] Source: Calculated by the author from standard reference books on food composition.

fish. For the calorie-conscious, it is valuable to know that 200 g. of cod fillets carry 140 calories, while beef, with the same amount of protein, has 170–220 calories and pork 500 calories (Kraut, 1957).

Through an average serving of 200 g. of fish fillet (or 300 g. of fish with bone), the percentages (Table VII) of the daily requirements of an adult (150 lb.) are provided. Lean fish differs somewhat from fatty fish. Only nutrients representing more than one-tenth of daily needs are included (Kraut, 1957).

TABLE VII

NUTRIENTS PROVIDED BY AN AVERAGE SERVING OF FISH[a]

Nutrient	Requirement	Fat fish (%)	Lean fish (%)	Vitamins	Requirement	Fat fish (%)	Lean fish (%)
Protein	75 g.	50	50	A	5000 IE	100	—
Fat	80 g.	60	—	B_1	1.7 mg.	15	15
Calories	2,600	25	5	B_2	1.8 mg.	30	20
Phosphorus	1.5 g.	45	40	Niacin	12 mg.	75	50
Iron	12 mg.	30	25	D	400 IE	1000	—

[a] From Kraut, 1957.

Based on the rule that at least one-third of the protein intake should be in animal protein, a fish serving readily fulfills this specification. To what degree this satisfies the amino acid requirement was analyzed in Chapter 2, Part I.

Fermented fish products go back to Roman days and their "garum." This was presumably very similar to the so-called sauces manufactured throughout Asia, constituting fish which is bacteriologically and enzymatically broken down under the strict control of table salt. Proteolysis is the leading process, yielding amino acids which are readily available for supplementation. Because of their high lysine content, they are particularly valuable in an extreme vegetarian diet. These fish sauces also add to the amount of sulfur-containing amino acids (Rérat and Jacquot, 1956). The salt as such constitutes another beneficial asset of these very diets (Toury *et al.*, 1958) (see also this volume, Chapter 2, Part I, and Volume III, Chapter 20 by van Veen).

As pointed out by Deas and Tarr (1947) bread, prepared from flour, in the form of two 1-lb. loaves, furnishes as much tyrosine as is found in 1 lb. of fish flesh; three loaves are equivalent to this amount of fish with respect to tryptophan, and five loaves are needed to convey a comparable amount of threonine. The greatest discrepancy prevails with regard to lysine. It would take eight loaves of bread to supply as much lysine as occurs in 1 lb. of average fish flesh. This EAA is the chief limiting factor. Pound for pound, fish can be said to be eight times more valuable than bread in supplying this essential dietary factor. Fish flesh, however, lacks almost completely the carbohydrate constituents so characteristic of many foods of plant origin.

H. Consumption

Despite the growing world population, the per capita consumption of fish is increasing more rapidly. Fish is unique in this respect when compared to other food commodities. This can be confirmed through available statistics. This shows the increasing dependence on fish in the feeding of the human family. It might also signify that the fishing industry is getting better organized. Because of this, the catches are more readily recognized in commercial statistics.

There are, nevertheless, some exceptions to this general rule. Declines in per capita figures are reported from such countries as the United Kingdom, Haiti, and other Caribbean islands. The causes are completely different: in the first case, ample provision with other animal foods and in the second, the extreme shortage of food chiefly due to excessive population growth.

The growing prevalence of fish in human diets does not necessarily mean that fishery is more successful than agriculture in keeping pace with the population growth. It may reflect the fact that the population pressure is inducing more efficient catching, largely by resorting to the exploitation of yet untapped resources. Paradoxically enough, it may also be the consequence of an accelerated urbanization—people moving to the cities, where fish in general is more readily available to more people. Mankind's greater degree of dependency on fish as food constitutes a double challenge, on one hand, the need of better protection of fish resources, and on the other, improved methods of preservation. In many countries (e.g., Korea) there is a marked discrepancy between the commercial catches and the actual consumption of fish. This is chiefly explained by the extensive spoilage of landed fish in peak seasons. This raises the very important question of the utilization of fish, which has a vital influence on the standing of fish in world nutrition. Trends in this respect will be analyzed in Chapter 19 of this volume.

I. Price

In most countries, fish is cheap in comparison with other protein foods. In 1950, the price to United States farmers for livestock varied from 18 cents per pound for pigs to 23 cents for beef cattle. The total of all fish in the United States was produced and sold by fishermen on the average at about one-third the price paid to farmers for competing meat protein (Taylor, 1953). Basically, this is explained by the absence of any productional costs. The investments and costs are limited to the capture, handling, and processing.

Over the entire globe the major common species of fish offer protein that is cheaper in price than most other animal products. Kraut (1957) established that the protein in marine fishes costs half that of beef and one-third that of pork. Milk protein was comparable in price. Employing a residual method, it was established that the price of fish protein was persistently less than that of other animal protein with the exception of milk, when attaching to the fat the retail price of oleomargarine and to carbohydrates the retail price of ordinary white sugar (Borgstrom and Almgren, 1953). Cod protein was approximately twice as expensive as herring protein, but all investigated fish protein was considerably below the price of eggs, pork, and beef. Meier (1956) also employed the sugar price, but for fat used the price of lard. Even in this case, fish belonged to the low-cost items in comparison with most other animal foods. Exceptions were evaporated or dried milk and pork sausage. Hamburger was more expensive than fish fillets. A United States study established that expenditure varied inversely with the cost of proteins, fish being the least favored animal food in this respect (Ministry Agr. Fisheries and Food, 1960).

In most countries, herring and sardines are coveted foods. Dried cod is another very cheap item. Besides, the fish protein cost in man-hours are about half those of pork in a well-advanced agriculture—and still pork in most countries is the cheapest of the land-animal proteins when the hogs are not raised on skim milk. When computing the labor involved, fish, even in this respect, stands out as among the least costly of animal protein foods.

II. Aquatic Production and World Feeding

A. GENERAL

Maritime nations long ago realized the importance of fish and seafood to human nutrition. In West Africa, the Far East, and some Pacific islands, population groups subsist almost exclusively on fish and plant products. No obvious nutritional deficiencies have been detected there. The nutritive attributes of fish have, consequently, long been recognized and well established as empirical knowledge of the human race. Nowadays this knowledge is firmly endorsed by chemical analyses, clinical findings, and nutritional experimentation. Fish is an important source of protein and in addition it provides essential minerals and vitamins and, in not a few cases, fat at low prices. It is of high value in the diet of human beings and livestock. Furthermore, the fish flesh has a delicate structure and is easily digested.

Considering the entire world population, the average yearly consumption of aquatic products at present amounts to 10 kg. per person. In addition, 3 kg. per person are utilized in other ways but usually end up as food via meal, as refined oils in the margarine industry, or as fertilizers.

In prewar days, British fish accounted for only about 10% of the animal and 5% of the total protein intake. Nevertheless, the United Kingdom fish catch, in amount of protein, exceeds its importation of meat from Argentina (92,000 as against 55,420 metric tons). The Norwegian herring catch in recent years equals the meat yield from 1.6 million cattle (it used to be 2.25 million) and the cod catch, 500,000 cattle. The cattle stock of Norway is 1.1 million units. The Pacific landings are equivalent to the meat from more than 51 million cattle (Borgstrom, 1962a).

Fish consumption has been analyzed above. Noteworthy here is the fact that most countries show a trend toward a higher per capita intake. But in better-fed countries the situation has been rather stagnant and in a few, such as the United Kingdom, there is a decline in this respect. In principle, a better utilization of the catches through preservation and improved handling should induce an enlargement of consumption. For various reasons, discussed in Section IV of this chapter, this has not always been the result. An earlier analysis of this aspect was given by Borgstrom (1951).

1. *Asia*

Dietary lack of high quality protein from animals sources constitutes one of the major nutritional problems in several areas of the world, e.g., large parts of the brim of Asia. A large number of people with limited means obtain their caloric requirements chiefly from rice and other similar cereals. Fish thus constitute a readily available source of cheap, supplementary protein.

Fish constitutes the principal protein food of a large majority of the people of the Philippines. Approximately 2,000 species of fish are found in these waters, most of which are edible (Valenzuela, 1928).

The highest number of calories per 100 g. of the fish was obtained from the fish called "mayamaya" (red snapper), which gives 145.5 calories, and the lowest, 72.7 calories, from "dilis" (*Stolephorus commersonii*) or long-jawed anchovy. Being cheap, this fish is available to all, irrespective of purchasing power. Sometimes it is made into a fish paste called "bangoong." The raw fish is commonly salted and dried and is either toasted or fried for food. Plain roasted bañgos (milkfish), a common ingredient in daily food in the Philippines, contains protein in excess of 30% (Valenzuela, 1928).

Fish sauces are extremely important dietary supplements in the entire Southeast Asian region (Autret, 1948; see also Chapter 2, Part I, this volume, and Volume III, Chapter 20 by van Veen). Local raising of fish in ponds is another readily available source of fish which is regularly added to the daily diet—see Section I, B, 3.

2. *Brazil*

The mussel *Mytilus munahenis*, which is so common in brackish lagoons or lakes at several places along the Brazilian coast, constitutes the only source of cheap animal protein to the poor, economically weak group of the population. It is equal to casein in nutritional value (de Siqueira *et al.*, 1954). It is preserved through drying.

3. *Tropical Africa*

Most of the dietary protein of Africans in Nigeria is supplied by maize. This is deficient in tryptophan and lysine, without which essential amino acids of the protein ingested cannot wholly be utilized by the body. Many are living on a diet grossly deficient in animal protein, and markedly lacking in non-animal protein. Clinical evidence also points to protein deficiencies as being very common among the general population of Nigeria. Dietary surveys indicate that pregnant women frequently receive only 1 oz. (28 g.) of meat or fish per day or even less (Nicol, 1952). Fish eating tribes are as a rule better nourished, their intake of animal protein being greater than that of adjacent farming or trading groups. This also reflects the better state of general health (Nicol, 1952). Similar findings are reported from Senegal when comparing fishing and farming villages in the Dakar region (Senecal *et al.*, 1956).

Similar conditions of protein deficiencies are reported from Ghana (Mayer, 1959). Fish appears to offer the best possibilities to meet this challenge.

The artificial raising of *Tilapia melanopleura* has in recent years brought fish to the island of Madagascar where the protein-deficient diet was prevalent. In areas along the rivers and lakes stocked with *Tilapia* and in the central regions with its numerous cultivation ponds this fish is now consumed in substantial quantities—the intake per day is greater than the average European intake per week (Anonymous, 1960a).

4. *The Arctic*

For countless generations, Eskimos in the circumpolar area have fished Arctic lakes and coastal areas of northern oceans on a subsistence basis. Seals, together with fish (pike, arctic char, etc.) were the basis of their food (Abs, 1959). The polar bear, also providing meat and vitamins, in turn feeds on fish.

B. Per Capita Consumption and Calories

Based on the total world catch of approximately 39 million tons (1961) of fish and shellfish, this category of food commodity does not seem to be too important. Divided among the three billion people now living, fish amounts to approximately 11.7 kg. (23.4 lb.) of fish and 1.3 kg. (2.9 lb.) of shellfish per capita per year. One-fifth (22.5%) of the total catch is utilized as feed and for purposes other than human food. In terms of edible flesh, this means 5.0 kg. (11 lb.), 13% of which refers to fresh-water products. But it does not seem adequate to evaluate world supply of fish on such a sweeping basis. The regional differences are too large and the consumption habits vary too much to justify calculations of such a general nature.

The significance of fish to the national diet of each country is most frequently gauged on the basis of the annual per capita intake of edible fish in each country. Heading the list based on statistical data of 1960 (Table VIII) we find Angola and Portugal with 32-28 kg. Japan has overcome the decline of the war years and regained her prewar figures, now attaining 22.5 kg. The two Scandinavian countries, Norway and Sweden, are quite high and have for a number of years surpassed even the per capita figures for Japan. Nevertheless, it is obvious that fish is far more essential to Japan than to the Scandinavian countries. Other good examples of such discrepancies between statistics and the importance of fish are countries like India, Pakistan, and Indonesia, where fish is far more essential than the consumptional data seem to indicate. This fact, together with other considerations, indicates that the per capita figures constitute no suitable yardstick for an evaluation of the true role of fisheries in the economy, nor in the actual feeding of a country. Such figures give absolute information but reflect only slightly the relative standing of fish in the food balance of each individual country.

Table VIII

Consumption of Fish in Selected Countries (1959)[a]

Country	Fish protein (kg/year)	Edible fish flesh (kg/year)	Country	Fish protein (kg/year)	Edible fish flesh (kg/year)
Angola	5.69	31.5	Greece	1.44	8
Portugal	4.96	27.6	Israel	1.26	7
Japan	4.05	22.5	Canada	1.31	7.3
Norway	3.47	19.3	Finland	1.28	7.1
Surinam	3.28	18.2	New Zealand	1.08	6
Korea	3.21	17.8	Soviet Union	1.20	6.7
West Indies	3.10	17.2	Belgium	1.08	6
Sweden	3.03	16.8	Venezuela	1.44	8
Burma	2.77	15.4	China[b]	1.10	6.1
Taiwan	2.74	15.2	France	1.02	5.7
Thailand	2.48	13.8	Italy	0.72	4
Philippines	2.34	13.0	Peru	0.90	5
Cambodia	2.10	12.0	United States	0.91	5.1
Denmark	2.08	11.6	Indonesia	0.88	4.9
Malaya	2.04	11.3	Netherlands	0.84	4.7
Chile	1.79	9.9	Pakistan	0.80	4.4
Congo (Belgian)	1.74	9.7	Poland	0.73	4.1
Spain	1.72	9.6	Nigeria	0.67	3.7
United Kingdom	1.61	8.9	India	0.62	3.4
South Africa	1.50	8.3	Brazil	0.40	2.2
West Germany	1.35	7.5	Mexico	0.25	1.4

[a] Source: Food and Agriculture Organization statistics.

[b] Estimate.

The validity of this criticism is borne out by two examples. Japan, known as a country for which fish is indispensable, can muster only a petty 3% in such a computation. Italy has a percentage figure (0.8) almost identical to that of the United Kingdom, in spite of the fact that the latter country consumes twice as much fish.

Calculations of this nature have given rise to the notion that fish is nonessential, both on a national and global scale. According to some writers, fish could easily be replaced by agricultural commodities. There would undoubtedly be no great difficulty in almost any country on earth to attain a 2–3% increase in the total agricultural production and thus theoretically make fisheries superfluous. The only way to make a sound appraisal of the place of fish is to recognize this commodity as a source of animal protein and compare it nutritionally with equivalent items, such as milk, meat, poultry and eggs. It is true, nevertheless, that, judged on statistical figures, the final catch is negligible, and seafood only constitutes a trifle of the world's total intake of calories—approximately 1%.

C. Fish and Shellfish as a Protein Source

1. *General*

In all evaluations of fish as a food source, main emphasis is put on the protein—less on fat. This applies no matter which sphere is examined, whether it be fresh fish or by-products for animal nutrition. In their total aminogram and their content of EAA, most fish proteins also compare most favorably with other animal protein. They unquestionably can be described as a high-quality protein requiring little supplementation—see further Chapter 2, Parts I and II, in this volume.

The present direct consumption of 5.0 kg. (11 lb.) of fish and shellfish flesh per capita would contain 900 g. of protein, constituting 41 days' supply of animal protein at the present average consumption level of the world, i.e., 3.5% of the actual total protein consumption and 9.4% of the animal protein intake. Shellfish would comprise 0.5 kg. of this total of 5 kg. Taking into account the protein indirectly produced through fish-containing feedstuffs, the given values could increase approximately 4.5%, consequently of minor significance on this general basis.

2. *Fish and Shellfish as Animal Protein*

When comparing fish on a global basis with other animal proteins, its relative position is clearly manifested. Meat provides only twice as much protein as fish, and milk approximately 3.5 times. Eggs, together with poultry meat, account for less than fish provides. As fish is the primary source of animal protein to nutritionally low-standard nations, it feeds—i.e., fills the gap between starvation and subsistence—far more millions than does either milk or meat. More than two-thirds of all meat and milk is consumed by less than 60 million people. But over 1,500 million humans depend on aquatic foods for more than half of their average daily animal protein.

TABLE IX

FISH IN PROTEIN BALANCE OF SELECTED COUNTRIES (AVERAGE FOR 1957-1959)

Country	Fish protein (grams per day per capita)	Animal protein (grams per day per capita)	Fish protein (%)
Austria	1.6	42.2	4.0
Belgium	3.5	44.0	8.0
Eire	2.1	51.4	4.0
France	2.8	45.9	6.1
Greece	3.7	21.0	17.6
Italy	2.8	25.9	10.6
Netherlands	2.3	45.1	5.1
Portugal	13.6	23.2	58.4
Spain	4.7	20.0	23.5
United Kingdom	4.4	49.0	9.0
West Germany	3.7	43.5	8.5
Denmark	7.1	53.1	10.7
Finland	5.8	68.4	7.2
Norway	9.5	50.4	18.9
Sweden	8.3	57.0	14.6
Soviet Union	3.3	33.0	10.0
Canada	3.6	62.9	5.1
United States	2.5	66.0	3.8
Mexico	0.7	17.5	4.0
Costa Rica	0.7	21.2	3.3
Cuba	0.7	28.7	2.4
Dominican Republic	1.9	12.7	11.0
Haiti	0.7	5.0	14.0
Honduras	0.7	8.9	7.9
Argentina	1.0	56.6	2.0
Brazil	1.1	24.3	4.5
Chile	6.5	26.9	18.2
Colombia	0.7	20.2	3.5
Ecuador	1.4	10.9	12.8
Peru	2.8	13.2	21.2
Venezuela	6.7	24.2	27.6
Burma	7.6	13.0	58.5
Ceylon	2.7	6.2	51.0
China[a]	3.0	10.0	30.0
India	1.7	6.6	25.7
Indonesia	2.4	4.8	50.0
Japan	11.1	17.4	63.8
Pakistan	2.2	5.7	38.6
Philippines	6.4	11.4	56.1
Taiwan	7.5	12.8	58.6
Thailand	7.1	29.5	24.0

[a] Estimate.

TABLE IX (*continued*)

Country	Fish protein (grams per day per capita)	Animal protein (grams per day per capita)	Fish protein (%)
Egypt	2.6	12.9	20.2
Israel	3.7	30.5	12.1
Turkey	0.7	14.5	4.8
South Africa	4.1	30.8	13.3
Australia	1.9	58.7	3.2
New Zealand	3.5	70.1	5.0

A second, common procedure in establishing the role of fish in protein terms is to calculate for each individual country the percentage of the total animal protein intake which can be attributed to this commodity. Such figures have been computed by the author for most countries of the world. A selection of such data is listed in Table IX. By this method fish stands out far more clearly as an essential, almost indispensable, source of animal protein. Consequently, figures of this kind constitute far better indicators of the place fish is holding in both the national and the global diet.

Even in such generally well-fed Scandinavian countries as Norway and Sweden, 16–17% (approximately one-fifth) of the total animal protein consumed can be ascribed to fish. This is approximately the same ratio found in several South American countries such as Chile, Peru, and Ecuador. One-fourth of the animal protein intake is represented by fish in such countries as Spain and India; this figure rises to about one-half in the case of Ceylon and Indonesia. Portugal and Japan constitute the next group, where almost three-fifths of all animal protein is of fish origin. Thailand comes close to three-fourths in this respect. Extreme cases are represented by Jamaica, where 85% of the animal protein consumed comes from fish, no less than 93% of which is imported (Borgstrom, 1938).

Table X allows a comparison of animal protein intake in relation to other animal foods. Numerous interesting observations can be made on the basis of this listing. Space allows only two comments. Judged this way, the following countries are leading fish nations, namely, Portugal, Japan, Taiwan, and Ceylon, although the latter is on a low total protein level. In a number of countries, fish is more important than eggs and poultry, e.g., Scandinavia, Portugal, Japan, Taiwan, Chile, and South Africa. Japan obtains two times as much protein from fish as from milk.

One cannot, however, be satisfied with figures of this general nature. They disregard the appreciable differences prevailing as to nutritional standards between countries, as measured by the total amount of animal protein being consumed annually. The United States is in the top with 66 g. per capita per day (51 lb. a year). At the other end of the scale we find low-protein countries like China, India, Indonesia, etc., where the daily intake is down to one-tenth of the United States figure. New Zealand shows 70 g. per capita.

TABLE X

ANIMAL PROTEIN BALANCE IN GRAMS PER DAY PER CAPITA (1954-1957)

Country	Animal protein	Fish	Milk	Meat	Eggs and poultry	Plant protein	Total
Belgium	44.0	3.5	17.0	18.1	5.2	43.8	87.8
France	47.2	3.1	15.3	23.4	5.4	48.1	95.3
Greece	21.0	3.7	12.1	5.7	2.0	59.5	83.0
Italy	23.5	2.8	10.3	7.3	3.1	50.4	73.9
Netherlands	42.8	2.3	23.1	14.1	2.8	35.8	78.6
United Kingdom	49.0	4.4	19.2	20.1	5.2	36.1	85.1
West Germany	42.6	3.7	18.7	16.5	3.7	35.6	78.2
Portugal	23.2	13.6	2.2	5.8	1.4	46.5	69.7
Denmark	56.1	7.1	25.5	20.3	3.2	38.7	94.8
Norway	50.4	9.5	25.2	13.1	2.6	38.0	88.4
Sweden	57.0	7.1	28.9	17.3	3.4	30.2	87.2
Ceylon	5.9	3.0	1.4	1.1	0.4	36.8	42.7
India	5.3	0.5[a]	4.2	0.5	0.1	45.0	50.3
Israel	30.5	3.7	14.5	4.2	8.1	57.3	87.8
Japan	14.5	10.5	1.0	1.6	1.4	47.9	62.4
Taiwan	12.8	6.9	0.1	4.7	1.1	39.7	52.5
Turkey	14.5	0.7	8.1	4.6	1.1	74.0	88.5
Canada	62.9	3.6	24.9	24.7	9.5	34.3	97.2
United States	66.0	2.5	25.1	27.5	11.0	28.1	94.1
Argentina	56.6	1.0	12.8	39.5	3.1	40.1	96.7
Brazil	18.0	0.9	4.7	10.5	1.8	44.1	62.1
Chile	28.4	6.5	8.2	11.8	1.7	50.9	79.3
Egypt	12.9	2.6	5.1	4.1	1.1	61.7	74.6
South Africa	30.8	5.7	7.9	15.8	1.4	43.6	74.4
Australia	58.7	1.9	17.2	34.5	4.8	31.8	90.5
New Zealand	70.1	3.5	26.5	34.9	4.9	33.3	103.4

[a] Presently more than twice this amount (see also Table IX).

Thus, even from a limited nutritional point of view, the figures discussed so far convey only fragmentary information. More adequate methods for appraisal were desirable, especially when geographic and economic factors were to be brought into interplay with these sets of nutritional data. New approaches to this problem and alternative suggestions for evaluating the role of fisheries were formulated by the present author in a recent study (Borgstrom, 1961d, 1962b).

3. *Fish in Total Protein Balance*

The world shortage of protein is critical. This constitutes a major challenge to the world's fisheries. The total world use of protein to feed the human family was, in 1959, approximately 84.6 million tons but increasing at the rate of 1.7% a year, which means at least 14.5 million additional tons in 1970, and still nothing is brought in to alleviate the present shortage. Consequently, all these quantities are based on the present deficient nutritional status of the world. This is what is needed merely to avert further deterioration of the grave protein situation.

To what extent do present world fisheries contribute to this average protein intake of the world? Out of the total catch of 39 million tons (1960), 30.8 million tons are available for human consumption, but only half of this—15.4 million tons—is in fact edible and actually consumed. A considerable amount goes to waste—the table waste is evaluated at 10%. At the most it would consequently mean 13.9 million tons which, with an average protein content of 18%, comes to 2.5 million tons of protein, i.e., 3.0% of the total.

A distinction should, however, be made between plant and animal protein, the latter being in general more complete as to its amino acid composition. Commonly plant protein, dominated by cereals, can be given a value of only half that of animal protein. On such a basis and in terms of high quality protein, the world's total intake would be 54.6 million tons—and fish, as belonging to the animal category, would then retain its figure of 2.5 million tons. The percentage role of fish in such a setting would be 4.5%.

But in the global balance of the world's total animal protein, fish accounts for 3.2 million metric tons out of a total of 24.5 million metric tons—namely, 13.1% of the total (Table XI). In contrast to other

TABLE XI
WORLD BALANCE OF ANIMAL PROTEINS

Food	Million metric tons	%
Milk	10.5	43.0
Meat	8.4	34.2
Beef	(4.5)	
Pork	(3.3)	
Mutton	(0.6)	
Fish	3.2	13.1
Poultry	1.0	4.1
Eggs	1.4	5.6
	24.5	100

animal proteins, a higher proportion of fish as compared to meat (meat meal, etc.) and milk (skim milk, whey, etc.) is employed in animal feeding and does not directly enter into human consumption. This figure is thereby reduced to 9.5%.

4. *Fish in Primary Protein*

Another way to appraise the relative standing of fish is to resort to a calculation of total primary protein. For the production of terrestrial animal protein an average conversion factor of 7 seems reasonable. This is discussed in more detail by Borgstrom (1962b).

Out of the total animal protein quantity of 24.5 million metric tons, 21.1 million tons refer to terrestrial animals. This means that 147.7 million tons of primary plant protein is contained in the total of all feedstuffs devoured by livestock in order to produce animal food products on land. In addition there would be the protein in the feed eaten by draft animals; this is 30 million tons.

It has been generally overlooked that fish, despite its far smaller amount, in effect utilizes a far larger quantity of primary protein for its making, due to the lengthy conversion chains in the sea. The conversion efficiency of the aquatic environment is generally considered not to go below 5 in the first conversion from primary plant products (phytoplankton and algae) and not below 10 in subsequent conversion stages. There is a great deal of evidence that these conversion factors are actually larger, but restraint is shown in these calculations in order to arrive at safe minimum figures of a realistic nature. Taking this figure, and also recognizing the fact that the number of links in the seas is greater—at least 3 (herring) and frequently 5 (cod)—one reaches the staggering figure of 32 billion metric tons of primary protein, using a medium figure of 4 links. In other words, the present fish catch is bringing into the human realm on earth an amount of primary plant protein which is 216 times larger than that used by the entire agriculture of the earth.

There is a certain degree of tertiary production in agriculture via hogs, poultry, calves and others being fed various animal products. What this means in terms of additional primary protein is being computed by the present author, but no final figures can be given at this time.

To what degree there is a feedback into the productive links of the seas in a briefer period than one year is only scantily known. At any rate, such a short-circuiting would naturally reduce the above huge figure. But even so, it will unquestionably mount far above the corresponding figure for agriculture, as being of an entirely different magnitude.

5. *Protein Deficiency and Fish*

The first case of a disease resembling kwashiorkor can be traced back to Yucatan in Mexico (Correa, 1908). It was called "culebrilla" and was characterized by diarrhea among young children, skin lesions, and edema of the legs and feet. It was usually fatal. It was decided that culebrilla was clearly distinct from scurvy but, notwithstanding, was related to malnutrition.

A few years later, Guillon (1913) in French Indo-China began studying Annam swelling ("bouffissure d'Annam"). This disease occurred only among coolies and poor agricultural laborers. It had never been seen among the upper classes, nor among those who lived by the sea and ate fish.

From the end of World War I until Williams (1931-1932) gave her classical description of kwashiorkor, many odd diseases were described which later have been identified as protein deficiency diseases of either the marasmus or the kwashiorkor type. Gradually tropical parasites were ruled out as the primary causative agents (Brock and Autret, 1952).

In other places, where fish is a considerable part of the diet of the child, it may be protected against kwashiorkor. The absence of kwashiorkor in coastal districts of Central America and West Africa is attributed to the consumption of fish (Autret, 1953), and the opportunities for obtaining fish, either fresh or dried, are a possible reason for a better state of nutrition in children in some of the coastal districts of Kenya as compared to the hinterland (Trowell *et al.*, 1954).

6. *Special Products*

Fish protein is incorporated into the human diet not only via the visible direct consumption of fish flesh, fresh or preserved. In many parts of the world more sophisticated fish products or elaborate fish dishes have emerged. Several of these are important outlets for fish protein or its amino acids. The fermented items so commonly encountered and used in the entire Southeast Asian region are reviewed in Volume III, Chapter 20.

Fish macaroni is one such product devised by Indian scientists for home-cottage production or large-scale industrial manufacture.

French nutritionists have concocted a special biscuit containing several proteins from corn, groundnuts (peanuts), dry milk, dried yeast, and coconut. Moroccan fish flour has no other ingredient (Mauron *et al.*, 1960). Fish is the major source of lysine in this special type of flour, and, together with milk, it provides most of the methionine. This combined product maintains its lysine content both in storage and manufacturing better than the individual ingredients do when treated in the same way.

a. Fish Meal

It is deplorable that fish meal, at the present time, is not wholly converted into direct use as human food. This is primarily due to technical reasons. Furthermore, there is heavy competition between the domestic animals of the well-fed parts of the world and human beings in these developing areas. Agriculture is given almost entire credit for the flourishing postwar animal production of Europe. This is only partly justified—a major factor is the channeling of animal protein through the back door via fisheries. Few realize that several major European countries feed more fish protein to their domestic animals than they do to the human beings. This is true for Denmark, West Germany, the Netherlands, Norway, and the United Kingdom. It is most surprising to find in this same category South Africa, a country where a large portion of the population is seriously short of protein.

The United States is, next to Peru, the largest producer of fish meal, but is nevertheless buying on the world market more fish meal and fish solubles than any other country. In terms of protein, this importation amounts to approximately one-seventh of what currently is totally consumed in meat and as much as two-thirds of what is available as poultry meat! No less than approximately one-third of the United States broiler meat production can in effect be attributed to the sea. Half of this marine feed is imported. The United States constitutes the major market for world fish meal, surpassed only by Europe when all individual countries there are added together.

This United States purchase of protein could, in fact, satisfactorily fill the protein gap of the highly protein-deficient South American continent (Borgstrom, 1958). A channeling of the fish protein now used as feed for domestic animals into human use could appreciably improve the poor protein standard in many regions and indirectly enhance productivity. Great importance consequently must be attached to the present efforts toward improving and expanding the manufacture of fish flour which can be used as a supplement in breads, soups, puddings, etc. Undoubtedly such fish protein would constitute an excellent basis for world-wide relief.

This protein deficit is worth observing in discussing economic balance and surplus problems. On the basis of the experience of Japan and most European countries, it is correct to assume that agriculture in Latin America would hardly be able to provide sufficient protein to feed the rapidly growing population, particularly if the nutritional standard is going to be improved in those many countries which now live on a substandard level in this respect. Fish will not only be cheapest but also the most efficient way of ameliorating present conditions. This explains the great interest which today is attached to development of the fishery resources of Latin America. Surveys of the Caribbean area, however, clearly point to definite limitations. This presumably will always be a deficit area where cheaper protein in the form of milk products or fish protein will have to be imported from other regions more favorable to protein production. Promising improvements are, however, reported from Chile, Peru, Brazil, and Venezuela. Brazil today imports almost half of the fish protein presently consumed. This explains the current efforts to utilize more effectively both the sea and fresh-water resources of this great country (Beatty, 1960). The climate, the distribution and the composition of the fish fauna, the large distances, and several additional factors explain the slow progress being made. Several good enterprises have ended in failure because of negligence of one or the other of these basic factors. Drying is by far the most preferable and cheapest method of preservation.

Research has shown that fish meal and condensed fish solubles contain substantial amounts of vitamin B_{12}. This explains the special value of fish as a supplement to vegetarian diets. The more agricultural production is compelled, for the sake of better acre utilization, to increase further the output of plant products as a valid substitute for animal protein, the more vital does the availability of B_{12} become to human nourishment. This puts fish and fish products in a key position. The most recent discoveries of efficient methods to isolate B_{12} from sewage wastes may, however, partly change this situation.

b. Insulin

The whaling industry nowadays provides a substantial quantity of insulin. According to South African discoveries, the pancreas of shark also contains a very high percentage of insulin. One hundred and thirty sharks produce the same amount as is obtained from 400 to 500 cattle.

c. Fertilizers

To what extent fish and fish waste are used as fertilizer is difficult to establish and still more difficult to estimate is what additional food agriculture produces thanks to this source. Early in human history fish was utilized this way, in Brittany, on the minor islands of the British Isles (Aran, the Shetlands, the Hebrides), Norway, Maine, and other parts of New England.

This practice must not be overlooked, although it certainly played a far greater role in bygone periods of history when methods of utilization were less developed. Such use of herring in Scandinavia and Ireland, and salmon by New Englanders and North American Indians is well documented. Nevertheless, using the fish this way had its limitations since the potassium level in no way matched the amounts of nitrogen and phosphate present or added. Particular importance is attached to fertilizing with salt-water fish because the iodine generally penetrates the agricultural products grown on soil fertilized in this manner.

D. Fish and Shellfish as a Fat Source

1. *Fat Content*

The fat content of fish varies widely (Table XII). Generally fish are subdivided into three groups: lean, semifat, and fat fish, depending on the fat retention of the flesh. Contrary to terrestrial animals, excess fat generally is not deposited in the muscle tissue.

TABLE XII
CONTENT OF FAT IN FISH

Kind	Fat content (%)
Fish	
Lean	
Haddock	0.1–0.2
Cod	0.2–0.4
Sole	1
Plaice	0.7
Semifat	
Swordfish	3–5
Halibut	5.2–5.5
Baltic herring	2.1–6.5
Bonito	7
Herring, Atlantic	6–8
Mackerel	8–10
Fat	
Herring (in season)	12–26
Salmon	12–17
Tuna fish	13–18
Eel	9–20
Sardine	12–20
Shellfish	
Crab	1.4–1.6
Lobster	1.5–2.0
Oyster	1.9–2.2

The fat content varies a great deal depending on season, latitude, and sexual stage; e.g., the menhaden caught along the United States east coast in the north often show three times more fat in Canadian than in Mexican waters. The fat content of sprat falls steadily throughout the fishing season in both Scandinavia and the United Kingdom. The South African pilchard yields 16–17% oil in March and April, which falls to 2–4% in September and October. The body oil of menhaden caught in the Gulf is superior for use in the manufacture of oleomargarine compared to that of Atlantic menhaden (Borgstrom, 1961a).

There may, furthermore, be variations in the fat content that can be attributed to miscellaneous other factors (the time of spawning, the different seasons of the year, and fluctuations in feeding conditions) related to season and latitude. Fish are found to deposit the maximum amount of fat just before the spawning season, and to have a minimum fat content a few weeks afterward. The food supply also affects the composition of fish. When they are forced away from their accustomed feeding grounds by storm or by natural enemies, they are often encountered in very lean condition.

2. *The Fish-Fat Share*

The amount of fat obtained from aquatic sources is not negligible. Some idea of the direct contribution of herring fat to the total United Kingdom diet can be obtained from the 55,000 tons of herrings eaten there in 1956. On the basis of an average oil content of 10%, the edible portion would contain 2,750 tons of oil, or about 0.15 g./head/day over the entire population. This figure does not of course reflect its position among individuals who actually eat herrings or kippers regularly. The average Norwegian herring catch, half of which is used as human food, contains almost twice as much fat as all milk produced in the country and five times the fat in all meat. The position in other parts of the world could only be assessed after careful consideration of the local dietary habits and the species of fish.

On the other hand, a certain amount of the fish oil is not used for human consumption but for other industrial purposes. Exact figures on the total nonfood uses are not available. Furthermore, a substantial proportion of the total world catch of oily species of fish is converted into animal feedstuffs or hydrogenated for use in oleomargarine. Most of this oil falls under the statistical heading of "nonfood purposes," which is a misnomer, also applied to what goes into feeds and is converted into food. In the United Kingdom the domestic production of herring oil was 3,300 tons in 1956 (Herring Industry Board, 1956). Most of this oil would be hydrogenated and blended into edible fats. In contrast to herring eaten directly, consumption of the hydrogenated fat will be fairly evenly distributed. The conclusion is, nevertheless, inescapable that, apart from individuals and local areas, fish fats contribute little to the world's over-all supply of calories.

A substantial amount of oil is derived from fish-liver sources, particularly cod and in South African stockfish. In Norway more than 100,000 hectoliters of high-grade oil are produced annually this way.

The vital role played by whaling in the fat and oil supply of the world is discussed in Section I, B, 5.

3. *Tocopherol*

One complication to an unbounded broader use of fish oils in the human diet is the prevalence of highly unsaturated fatty acids. This in turn necessitates a higher intake of vitamin E in order to avoid disturbances in cattle, hogs, and poultry (see further Chapter 3). This relationship is carelessly overlooked in present-day recommendations for an expanded intake of polyunsaturated fatty acids. Several claims have been raised as to the beneficial effect of a fish diet due to the cholesterol-level reducing effect of various fatty fishes, e.g., sardines. These and other nutritive aspects of fish oils are subject to a detailed discussion by Tsuchiya in Chapter 7 of Volume I. There is further defined the possible consequences of the discrepancy between the content of polyunsaturated acids and essential fatty acids, frequently short in fish. It should be added, nevertheless, that most studies on the cardiovascular effects of fish oils have focussed attention chiefly on one variable—fat composition—and almost entirely overlooked the tocopherol content, which is most likely to influence decisively any cardiovascular syndrome. Few oils studied have been deprived of their tocopherol—a crucial undertaking—and all investigations with fish flesh as such have not taken this factor into account. There remains the likelihood that several of the observed beneficial effects are dependent on the presence of tocopherol or similar natural antioxidants rather than on the chemical constitution of the fats. A recent confirmation of cod liver oil inducing tocopherol deficiency is provided by Dehority *et al.* (1961).

E. Fish as a Source of Vitamins and Minerals

1. *Vitamins*

The nutritional significance of vitamins A and D from fish cannot be averaged over a national, or even less over the total world, population. Those who regularly take fish-liver oil medicinally may well derive the major part of their total intake of both vitamins from it. In areas where fish liver is commonly eaten, the same will apply.

The total landings of whitefish in the United Kingdom are equivalent to about 20,000 tons of liver oil, mainly from cod and similar species. If this were all available for human use, it could provide about 1000 I.U.

vitamin A and 100 I.U. vitamin D/head/day. The total current United Kingdom consumption of herring (55,000 tons in 1956) would, if evenly spread over this population, provide about 25 I.U./day of vitamin D (Lovern, 1958). Those individuals who fairly frequently eat herring or similar fish, e.g., sardines, obtain quite a high intake of vitamin D from these sources. One serving of herring provides half the daily need of vitamin A and vitamin D far in excess of daily doses (Kraut, 1957). Eels and lampreys are a potent source of several vitamins but particularly of the fat-soluble group. They enjoy long-standing recognition in this respect and were acknowledged for their health- and vision-restoring capacities long before vitaminology was born (see Higashi in Volume I, Chapter 13).

2. *Minerals*

Numerous statements are encountered as to the significance of fish as a source of mineral. A critical review of available analyses reveals, however, that extraordinarily few data are sufficiently accurate as to methods and analyzed parts to allow generalizations of this nature. The most common deficiency is the lack of clear definition of what has been analyzed—general terms such as "fish" and "edible parts" do not specify whether the parts under study were whole fish, raw or cooked fish, merely flesh, or whether the skin was included. The concept of edibility varies widely in different parts of the globe. The results as to mineral composition are greatly influenced by these factors. The skin has a composition quite distinct from that of the flesh.

Calcium. There are major differences in the calcium content between raw fish and boiled fish, and in the latter case between fish prepared as fillets or on the bones. In this instance, a substantial amount of calcium moves out into the flesh, and fish becomes, in contrast to flesh of terrestrial animals, an important source of calcium. The same is true in filleted or marinated fish. The calcium in fish is highly utilizable and as pointed out by Metta (1960) a fish flour supplementation at a 3% level would increase the average East Indian diet manyfold in this element. He also suggests improving the Multipurpose Food by the addition of fish flour, rendering a product not only with a high protein content (51%) but also with calcium exceeding 1%.

Iodine. It is frequently stated that fish constitutes an essential source of iodine. This, however, only refers to marine fishes. Fresh-water fishes are generally almost devoid of this element. The same is true of fluorine. Marine fish twice a week will provide the required minimum of both these elements. Iodine is also transferred via fish, seaweed mal, and fertilizers into eggs, milk, and vegetables (Lunde and Closs, 1936).

In a number of countries fish plays a decisive role in protecting the population from goiter. Most coastal areas of the world are free of this scourge, thanks to fish. In recent years, some doubt has been voiced as to the general validity of iodine as a preventive against goiter. This disease is still prevalent in large areas of the world and is not always eliminated by administering iodized salt or iodine-rich foods. In postwar continental Europe goiter blossomed and could not be subdued by iodine treatment. The goiter syndrome is obviously interrelated with a number of other factors; among these the vitamin A level seems to be essential. It still remains evident that iodine is required to avert goiter, but on the other hand, when vitamin A is inadequate, goiter may not be checked even with ample provision of iodine. This presumably explains why the island of Krk in Yugoslavia (Horvat and Marer, 1958) and many coastal rural regions of Japan still suffer seriously from goiter although their intake of iodine-rich salt-water fish provides all required iodine (Greenwald, 1958). There is also an interesting antagonism exerted by fluorine which might nullify the beneficial effect of iodine (Steyn, 1958). To what degree this effect applies to some fish, imbalanced in this respect, is not known.

Iron content is low in white-fleshed fish. Bleeding removes most of the iron-carrying pigments. Only fish with red meat can be compared to beef and pork in this respect. There are furthermore indications that raw fish contain a chelating or other agent that binds iron so strongly that this element is no longer fully available. Fur animals, fed such fish, have developed anemia (Anonymous, 1961b).

Sodium. Owing to the assumed detrimental effect of sodium on persons with heart deficiencies, the entire question of sodium in fish has come to the foreground. It has been taken for granted that the flesh of fish, grown and developed in an environment of high sodium content, should in a corresponding way be a rich source of this mineral. Extensive analyses, however, clearly indicate that most salt-water fish contain no more, and in many cases even less, sodium chloride than red meats. There is a clear selective absorption of the mineral elements from the sea. There are a few exceptions where sodium content is high, for instance, lobster, oyster, and red snapper. In cases where salt is added in the icing of the fish or the canning process, it is natural that the sodium chloride would far exceed the average values of fresh samples—30 mg./100 g. fresh meat (see further Chapter 5, this volume).

Fluorine. Salt-water fish generally contain 2–3 times more fluorine than the meat of terrestrial animals. Daily diets containing such fish consequently safeguard more readily the minimum requirements of this crucial element (Schweigert, 1960). Eskimos of the Pacific Northwest have superb teeth. This is attributed to their diet—comprising fish bones which contain 250 p.p.m. of fluorine (Harvey, 1945).

3. *Tristan da Cunha*

Several investigators found that the teeth of the isolated inhabitants of Tristan da Cunha had no more decay than those of ancient man (Sognnaes, 1954). Only 1.8–4.0% of all investigated teeth were carious. Their permanent teeth also contained 50% more fluorine than corresponding United States teeth (Minnesota). This was still more accentuated for the dentine layer.

The islanders were dependent upon local food sources for the bulk of their caloric intake. Fish and potatoes form their staple diet, while other foods play but a minor part. Many families were to a great extent subsisting on fish for a good part of the year. Approximate food intake per individual per day was:*

	Average intake in g. per day		Average intake in g. per day
Potatoes	728	Birds	47
Fish	248	Eggs	29
Crayfish	57	Milk (ml.)	26
Meat	57		

Fish provided their vitamin D needs but also fluorine in such ample quantities that in extreme cases fluorine mottling was observed (Sognnaes, 1954). But their fish consumption was also the highest on record. In those families studied, as much as 239–392 g. of fish (including shellfish) per individual and day was consumed, i.e., 73–140 kg. per year. Consequently, fish constituted one-third of the total caloric intake—far above any figure reported elsewhere. It may be roughly calculated that members of those families under study received 1.3–2.2 mg. of fluorine per individual per day from fish alone. Yet these families did not represent the greatest fish consumers on the island. The fluorine intake may, consequently, far exceed these values and show detrimental effects.

In all normal cases, however, marine fish constitutes an essential source of fluorine which in optimal quantities exercises a protective effect against caries in children and youngsters. In spite of a few instances where excessive amounts caused damage, fish obviously had this function on Tristan da Cunha. To a greater and lesser degree, marine fish must exert this effect in many other fish-eating nations. During the war years, when excessive carbohydrate intake was eliminated in Japan but fish consumption still was reasonably well maintained, caries almost disappeared as a general phenomenon.

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* The entire population was recently removed due to volcanic eruption.

III. Appraisal Methods

A. "Fish Population"

The figures stating the percentage of total animal protein represented by fish protein can be better conceived as to their significance if related to the human population. New methods of appraisal were tentatively presented by this author (1961). An answer was sought to the question: How many people does fish feed in each nation? In other words, on the basis of the current protein standard in each country, how many people could possibly fill their entire animal protein requirements from the amount of protein available through fish. This gives the "fish population" in each individual country. This figure, however, is not entirely correct. Some of the fish in the form of meal, solubles, etc., and occasionally also in the form of fertilizers, is used for producing a variety of human foods. In other terms, fish is utilized in the raising of poultry, pigs, etc., and thus indirectly contributes to the feeding of a country. As only very fragmentary statistical data are available as to the use of fish for fertilizing purposes, this aspect had to be deleted in this study. The amount of fish and fish products, calculated as protein which is used for such purposes (in cases where statistics are available) has been divided with a conversion factor of 5. This constitutes a reasonable average for different types of efficient food production through domestic animals (eggs, pork, milk, etc.) and where fish meal would be used. Thus we arrive at an additional number of human individuals who in this way are indirectly fed by fish. Table XIII lists a selection of these calculations.

From the entire material can be inferred that the world's total "fish population" exceeds 670 million, 535 million of whom are in Asia and approximately 50 million in Europe (excluding the Soviet Union) and 46 million in Africa. More than 21 million refer to the Soviet Union. Table XIII clearly bears out the far greater relative importance of fisheries to Asia. In the Pacific rim countries the fish population has been computed as 370 million. This must be interpreted correctly. Far more people actually eat fish in these areas but at the present state of affairs these calculated data indicate how many people could get their entire intake of animal protein from the fish protein available to each country, recognizing the particular dietary pattern of each such country (Borgstrom, 1961a). Portugal is the only country in Europe following an Asiatic pattern. It would be in a most precarious nutritional situation without having recourse to the harvest of the seas.

The Netherlands and New Zealand are noteworthy in that almost as many are fed indirectly by fish as directly. This ratio is still more extreme in the United States, namely 2:1. Several additional countries could be listed as providing more fish protein via feedstuffs than via human foods. In other words, by a direct human consumption they would, in effect, even when maintaining their present nutritional standard, be able to satisfy the animal protein needs of one-half (51%) of the present human population in Norway, almost two-fifths in Chile (38%) and one-third (30%) in Denmark, in the Netherlands and in New Zealand; around one-fourth of the total in such countries as Sweden (27%), the United Kingdom (24%), West Germany (23%), and Belgium (23%).

Several further observations could be made and interesting conclusions drawn from these data. Suffice it to underline that although these figures are most enlightening, they lack geographical explicity.

B. "Fish Acreage"

It is desirable to establish a relationship between the fishing industry and the natural resources of a country or region. Thus, by considering fish in agricultural terms, it should be feasible to relate fisheries to the productive capabilities of each individual country. This was done in a recent study by the author (Borgstrom, 1961d) by posing the following question: How many acres of tilled land would be required if an amount of animal protein equal to that obtained from fish were to be provided vicariously through milk? Answering this question involved a whole series of complex calculations. To simplify these, the assumption was made that skim milk was used for feeding domestic animals as a substitute for fish meal. This introduced a minor error, as naturally the butterfat produced simultaneously could be used for partially feeding a certain number of human individuals. For the moment, that point was ignored, but where this factor was analyzed it turned out that the oil of the fish used in meal production provided a corresponding amount and in several cases a larger quantity of fat than would be the case with milk (see further Table XIV).

In this way one obtains a clearer conception of the importance of fish to each individual country and the magnitude of the feeding burden which the fish industry is actually carrying. It also offers to the geographer a chance to conceive fisheries in concrete figures such as acreage and enables the agricultural economist to have at his disposal commensurate figures allowing a direct comparison between fisheries and agriculture.

On the basis of these calculated fish acreages, it becomes feasible to compare the role of fisheries in relation to agriculture and in turn to assess their importance in reference to the net importation—calculated in the same way as the acreage required to produce what is being imported on

Table XIII
Fish Population

	Human population (in millions)	Fish population			Percentage of total population
		Direct	Indirect	Total	
China	655	196,500	2,729	199,229	30
India	403	103,571	1,451	105,022	26
Soviet Union	210	21,000	420	21,420	10.2
United States	180	6,840	2,232	9,072	5
Japan	95	60,610	2,630	63,240	66.5
Indonesia	90	45,000	455	45,455	55
Pakistan	88	33,968	340	34,308	26
Brazil	65	2,925	30	2,955	4.6
West Germany	56	4,760	1,541	6,301	11.3
United Kingdom	53	4,982	1,537	6,519	12.1
Italy	50	5,400	189	5,589	11.2
France	45.5	2,685	244	2,929	6.4
Nigeria	35.5	4,225	—	4,225	11.9
Mexico	34	1,360	20	1,380	4.1
Spain	31	7,285	245	7,530	24
Turkey	27	1,296	24	1,320	4.9
Egypt	25	5,050	51	5,101	20.4
Philippines	24	13,464	216	13,680	57
Thailand	22	6,906	134	7,040	32
Argentina	21	231	4.5	235.5	1.1
Burma	21	12,285	106	12,391	59
Iran	20.5	263	—	263	1.3
Canada	18	1,026	109	1,135	6.3
South Africa	15	1,995	244	2,239	14.7
Colombia	14	490	5	495	3.5
Congo (Belgian)	14	6,650	55	6,705	47.9
Netherlands	11.5	587	539	1,126	9.8
Algeria	10.5	693	5.5	698.5	6.7
Sudan	10.5	63	2	65	0.2
Peru	10.6	2,247	46	2,293	21.6
Taiwan	10.5	6,153	64	6,217	59.2
Morocco	10.5	830	186	1,016	10.3
Australia	10.1	323	2	325	3.2
Ceylon	10.0	4,350	44	4,394	43.9
Belgium	9.5	750	286	1,036	10.9
Portugal	9.1	7,244	103	7,347	80.3
Tanganyika	9.1	1,265	28	1,293	14.2
Greece	8.3	1,461	130	1,591	19.2
Rhodesia	7.7	539	123	662	8.6
Chile	7.5	1,365	261	1,626	21.7
Sweden	7.4	1,258	138	1,396	18.4
Austria	7.1	114	71	185	2.6
Malaya	6.6	2,630	90	2,720	41.5
Cuba	6.6	158	4	162	2.5

TABLE XIII (*continued*)

	Human population (in millions)	Fish population			Percentage of total population
		Direct	Indirect	Total	
Iraq	6.6	125	1	126	1.9
Venezuela	6.4	163	3	166	2.6
Kenya	6.4	371	4	375	6
Switzerland	5.24	162	135	297	6
Ghana	4.91	1,120	4	1,124	23
Cambodia	4.85	1,910	26	1,936	40
Angola	4.56	3,126	38	3,164	69
Denmark	4.54	486	164	650	14
Finland	4.42	318	23	341	8
Ecuador	4.17	534	10	544	13
Tunisia	3.89	185	4	189	5
Guatemala	3.65	93	—	93	2.5
Norway	3.56	587	247	834	23
Haiti	3.46	485	10	495	14
Bolivia	3.42	295	—	295	9
West Indies	3.18	1,586	—	1,586	50
Dominican Republic	2.89	667	5	672	23
Eire	2.85	372	58	430	15
Uruguay	2.72	88	1	89	3.3
El Salvador	2.47	43.5	0.5	44	1.8
New Zealand	2.45	123	24.5	147.5	6
Israel	2.06	249	170	419	20
Honduras	1.89	149	2	151	8
Paraguay	1.72	21	—	21	1.2
Jordan	1.64	65	—	65	3.9
Nicaragua	1.42	57	0.5	57.5	6
Liberia	1.38	337	—	337	24
Costa Rica	1.13	37.2	0.4	37.6	3.3
Panama	1.02	38.9	0.4	39.3	3.8
Mauritius	0.62	144	—	144	23

a real basis. The figures in Table XIV show, on this basis, to what degree various countries rely on fish for the feeding of their population.

Countries depend on agriculture, fisheries, and trade for feeding. The fish and trade acreages constitute together the "ghost" acreage—a calculated area.

The acreage calculations are based on Food and Agriculture Organization figures and other sources as to the average milk-producing capacity (milk yield per head) related to acres. The obtained data are, in effect, minimum figures: they are based on the most efficient and, from the acreage point of view, in most countries the least costly way, in terms of acres, of producing animal protein. Secondly, on the assumption of an effective ley-farming with the added use of feed concentrates it would be

TABLE XIV
FISH ACREAGE

Country	Human food		Animal feed		Total acreage (1000 hectares)	Cultivated land (1000 hectares)	Fish acreage (%)
	1000 Tons fish protein	1000 hectares required	1000 Tons fish protein	1000 hectares required			
China	720	24,000.0	50	1,666.7	25,666.7	109,354	23.5
India	249.9	6,247.5	17.5	437.5	6,685.0	151,341	4.4
Soviet Union	252.9	5,059	24.3	506	5,565	219,700	2.4
United States	163.8	2,340	269.0	3,842.9	6,182.9	188,309	3.3
Japan	384.8	7,696.0	83.5	1,670.0	9,366.0	6,072	154.0
Indonesia	79.2	2,640	4.0	133.3	2,773.3	17,681	15.7
Pakistan	70.4	1,480.0	3.0	60.0	1,540.0	24,726	6.2
Brazil	26.0	866.7	1.0	33.3	900.0	19,095	4.7
West Germany	75.6	945.0	122.4	1,530.0	2,475.0	8,727	28.4
United Kingdom	85.3	1,066.3	131.6	1,645.0	2,711.3	7,126	38.0
Italy	51.0	850	7.9	131.7	981.7	15,809	6.2
France	46.4	773.3	21.2	353.3	1,126.6	21,325	5.3
Nigeria	23.7	790.0	—	—	790	22,317	3.5
Mexico	8.5	212.5	0.5	12.5	225.0	19,928	1.1
Korea	107.5	2,150	22.7	454.0	2,604	4,390	59.3
Spain	53.3	666.3	8.9	111.3	777.6	20,585	3.8
Poland	21.9	438.0	1.8	36.0	474.0	16,223	2.9
Turkey	6.8	170	0.5	12.5	182.5	24,070	0.8
Vietnam	12.5	312.5	0.6	15.0	327.5	3,038	10.8
Egypt	23.8	1,190.0	1.2	60.0	1,250.0	2,610	47.9
Philippines	56.2	1,124.0	4.5	90.0	1,214.0	7,296	16.6
Thailand	170.3	1,745.0	5.0	125.0	1,870.0	7,793	24
Argentina	5.5	110.0	0.5	10.0	120.0	30,000	0.4
Burma	58.2	1,455.0	2.5	62.5	1,517.5	8,582	17.7
Ethiopia	2.0	50.0	—	—	50.0	11,000	0.5

TABLE XIV (*continued*)

Country	Human food		Animal feed		Total acreage (1000 hectares)	Cultivated land (1000 hectares)	Fish acreage (%)
	1000 Tons fish protein	1000 hectares required	1000 Tons fish protein	1000 hectares required			
Iran	1.5	50.0	—	—	50.0	16,760	0.3
Yugoslavia	2.1	52.5	0.8	20.0	72.5	8,263	0.9
East Germany	9.5	190.0	2.5	50.0	240.0	5,184	4.6
Canada	23.6	314.7	12.3	164.0	478.7	40,600	1.2
South Africa	22.5	450.0	13.6	272.0	722.0	8,740	8.3
Colombia	3.6	120.0	0.2	6.7	126.7	4,843	2.6
Congo (Belgian)	24.4	697.1	1.0	28.6	725.7	49,020	1.5
Czechoslovakia	12.7	211.7	4.5	75.0	286.7	5,392	5.3
Netherlands	9.7	88.2	44.3	402.7	490.9	1,054	68.5
Algeria	5.1	127.5	0.2	5.0	132.5	7,076	1.9
Sudan	0.95	31.7	0.1	3.3	34.0	7,100	6.2
Peru	10.8	540.0	1.1	55.0	595.0	1,730	34.4
Taiwan	28.8	576.0	1.5	30.0	606.0	873	69.4
Morocco	5.8	145.0	6.3	157.5	302.5	8,218	3.7
Australia	7.0	140.0	0.2	4.0	144.0	23,173	0.6
Hungary	0.3	5.0	0.5	0.8	5.8	5,760	0.1
Ceylon	9.9	330.0	0.5	16.7	346.7	1,523	22.8
Belgium	11.4	114.0	21.7	217.0	331.0	990	33.4
Portugal	45.1	1,127.5	3.2	80.0	1,207.5	4,130	29.2
Tanganyika	4.5	112.5	0.5	12.5	125.0	2,800	4.5
Greece	11.2	353.3	0.5	16.7	390.0	3,530	11.0
Bulgaria	0.7	17.5	0.1	2.5	20	4,286	0.5
Rhodesia	2.8	70.0	3.2	80.0	150.0	6,383	2.3
Saudi Arabia	15.3	510.0	0.5	16.7	526.7	210	250.8
Chile	13.4	297.8	12.8	284.4	582.2	5,514	10.6
Sweden	22.4	280.0	12.3	153.8	433.8	3,712	11.7

TABLE XIV (*continued*)

Country	Human food		Animal feed		Total acreage (1000 hectares)	Cultivated land (1000 hectares)	Fish acreage (%)
	Tons fish protein	1000 hectares required	Tons fish protein	1000 hectares required			
Austria	1,900	31.7	5,900	98.3	130.0	1,771	7.3
Malaya	13,500	337.5	2,300	57.5	395.0	2,223	17.8
Cuba	1,700	42.5	2,000	5.0	47.5	1,970	2.4
Iraq	800	26.7	100	3.3	30.0	5,457	0.5
Venezuela	750	250.0	700	23.3	273.3	2,924	9.3
Kenya	200	40.0	100	2.0	42.0	596	7.0
Mozambique	260	86.7	20	0.7	87.4	2,000	4.4
Uganda	4,779	119.5	450	11.3	130.8	2,606	5.0
Madagascar	234	7.8	—	—	7.8	1,270	0.6
Switzerland	3,057	38.2	7,700	96.3	134.5	445	30.2
Ghana	5,013	100.3	90	1.8	102.1	5,310	1.9
Denmark	9,448	94.5	16,100	161.0	255.5	2,736	9.3
Angola	25,950	865.0	1,500	50.0	915.0	900	101.7
Finland	5,650	86.9	1,520	23.4	110.3	2,596	4.2
Cambodia	10,441	348.0	675	22.5	370.5	2,000	18.5
Ecuador	2,130	85.2	200	8.0	93.2	1,120	8.3
West Indies	9,850	246.3	19	0.5	246.8	457	54.0
Tunisia	710	17.8	65	16.3	34.1	4,912	0.7
Norway	12,336	176.2	24,700	367.8	544	850	64.0
Guatemala	280	11.2	10	0.4	11.6	1,473	0.8
Haiti	887	44.4	40	2.0	46.4	370	12.5
Bolivia	874	43.7	—	—	43.7	3,091	1.4
Liberia	620	15.5	—	—	15.5	1,902	0.8
Eire	2,183	36.4	1,700	28.3	64.7	1,399	4.6
Dominican Republic	3,088	123.5	100	4.0	127.5	680	18.8
Uruguay	1,989	39.8	100	2.0	41.8	2,552	1.6

TABLE XIV (*continued*)

Country	Human food		Animal feed		Total acreage (1000 hectares)	Cultivated land (1000 hectares)	Fish acreage (%)
	Tons fish protein	1000 hectares required	Tons fish protein	1000 hectares required			
Sierre Leone	840	21.0	—	—	21.0	3,662	0.6
Puerto Rico	—	160	—	22	182	256.5	71.0
El Salvador	165	4.1	—	—	4.1	544	0.8
New Zealand	3,132	44.7	15.0	2.1	46.8	485	9.6
Israel	3,358	111.9	11,453	381.8	493.7	392	125.9
Honduras	483	19.3	25	1.0	20.3	370	5.5
Paraguay	250	12.5	12	0.6	13.1	517	2.5
Jordan	234	11.7	—	—	11.7	893	1.3
Albania	300	10.0	30	1.0	11.0	353	3.1
Nicaragua	364	14.6	18	0.7	15.3	854	1.8
Costa Rica	288	9.6	15	0.5	10.1	281	3.6
Panama	262	10.5	13	0.5	11.0	450	2.4
Mauritius	786	26.2	—	—	26.2	84	31.2
Surinam	797	26.6	—	—	26.6	39	68.2

implied that the soil is adequately and intensively utilized. This justifies a direct comparison with arable acreage, disregarding pastures and other untilled soil. So in terms of acreas all these figures would in reality be much higher if such a transfer actually were executed and did not remain only a theoretical alternative.

The purpose of that study was, however, to find ways of measuring in readily conceivable terms the significance of fisheries; for that very purpose, and desiring to be on the safe side, such minimum figures were preferred. For huge countries like the United States and the Soviet Union, which cover a wide range of climate, soil, and varying agricultural efficiency, this computation has little meaning, but for all countries of reasonable size and uniformity in agriculture and climate these calculated figures are meaningful and enable direct comparisons to be made between countries of the significance of fisheries in relation to agriculture.

The glib talk about agriculture in various countries as "feeding" their population emerges as far less than correct. On the basis of the calculated fish acreage for Norway, it becomes evident that this country would have to expand its arable acreage by no less than 64% (2/3 tilled Norway added) and the United Kingdom by 33%, in order to take care of the production of a comparable amount of animal protein now actually used in the feeding of man and livestock in these two countries. Fisheries are, in other words, indispensable to their present standard of living. To a few countries, fisheries constitute their only means of survival. To this group belong not only Japan, Taiwan, and Thailand, but also, surprisingly enough, Israel, Egypt, and Puerto Rico. It should be underlined that this assertion is based exclusively on what is actually consumed by the respective populations, and consequently in no way covers what is being exported in terms of fish by these countries. What is landed by their fishing fleet or exported enters the statistics of the receiving and actually consuming countries. These figures reveal, too, that in countries like Peru and Chile fish already has acquired a very dominant position. To a degree these figures reflect the population pressure and are also useful for analysis of that nature. A new population density concept emerges which is being analyzed in a special book by the author (Borgstrom, 1962b).

In some Central American countries, and other areas which are compelled to import dried (bacalão), salted, or frozen fish to cover parts of their needs, the situation is most precarious. Several of these countries (Israel, Jamaica, Haiti, and Trinidad) would undoubtedly never be in a position to expand agriculture to the extent where it could provide the animal protein now acquired through fish (see Borgstrom, 1958).

Thus it becomes possible to measure the degree of dependence on fisheries, not in diffuse percentage figures but in concrete agricultural data. Nutritional improvements accomplished through agriculture may also be analyzed and compared to what can be achieved through fisheries. It also appears possible to establish geographical areas obliged to extend their reliance on fish resources.

It is essential to underline that these figures for fish acreages reflect the *current* level as to acre-yield and milk productivity in each individual country. Appreciable changes in this respect would naturally influence these data. It is furthermore evident that in most countries an expanded livestock production would have to move into less optimal conditions, implying the use of far larger areas, frequently less suitable than those now in use under the present, more ideal conditions. Furthermore, e.g., in both the United States and the Soviet Union, pastures would be involved and greatly enlarge the required additional acreage.

Nevertheless, the basis of these figures emerges as far more significant than the small percentage figures for calories seemed to indicate. These data for fish acreages are only part of the calculated "ghost acreages" which a great number of countries depend on for their feeding. The net importation represents a second major such item (see further Borgstrom, 1962b).

C. Fish and Animal Products

1. *Dairy Balance*

Another approach to this problem of appraising the true nutritional role of fisheries was presented by this writer (Borgstrom, 1962d) whereby the current dairy production in each country was used as a comparison. It should be observed that this figure is distinct from that which merely states the consumption of fish protein compared to that of milk. The entire use of fish protein, consequently the added amount of that for human food and that for the feeding of livestock, is matched against the current total dairy products which may not necessarily all be consumed but some exported. In this way it becomes feasible to state in percentage figures to what degree each individual country would have to expand their present dairy production in order to produce an amount of animal protein comparable to what is now obtained through fish. Many surprising facts unravel themselves through these data (Table XV).

In a few cases high figures in this respect reflect more the poor development of the dairy industry than the role of fishing. Such relative data cannot be justly analyzed when compared with figures indicating required additional acreages. A few comments are pertinent. Even in the United States, with its, relatively speaking, low fish consumption,

TABLE XV
FISH BALANCE IN DAIRY TERMS
(Increase required in present milk production to compensate for fish)

Country	% Food	% Feed	Total %
I. Group A (above 15%)			
Belgium	8.7	16.6	25.3
Greece	36.7	1.7	38.4
Italy	19.6	3.0	22.6
Netherlands	4.5	20.7	25.2
Portugal	455.6	32.3	487.9
Spain	62.9	10.5	73.4
United Kingdom	20.6	31.8	52.4
West Germany	11.9	19.2	31.1
Norway	21.3	44.7	66.0
Sweden	16.1	8.8	24.9
United States	8.2	13.4	21.6
Dominican Republic	147.0	4.8	151.8
Brazil	16.9	0.6	17.5
Chile	49.6	47.4	97.0
Ecuador	16.9	1.6	18.5
Peru	78.8	8.1	86.9
Venezuela	56.8	5.2	62.0
Burma	692.9	34.7	727.6
Ceylon	353.6	17.8	371.4
India	39.9	2.9	42.8
Japan	709.9	154.1	864.0
Pakistan	33.7	1.5	35.2
Algeria	43.2	1.7	44.9
Egypt	62.1	3.2	65.3
Israel	36.1	123.2	159.3
Morocco	20.2	22.0	42.2
Kenya	22.7	1.2	23.9
Rhodesia	93.2	106.8	200.0
South Africa	27.9	16.8	44.7
Tanganyika	104.7	11.6	116.3
Uganda	58.3	5.5	63.8
II. Group B (below 15%)			
France	7.1	3.3	10.4
Czechoslovakia	9.0	3.2	12.2
East Germany	4.6	1.3	5.9
Poland	5.5	0.4	5.9
Yugoslavia	2.5	0.9	3.4
Denmark	5.1	8.8	13.9
Finland	5.1	1.4	6.5

TABLE XV (*continued*)

Country	% Food	% Feed	Total %
Soviet Union	12.2	1.2	13.4
Canada	8.4	4.4	12.8
Mexico	8.3	0.5	8.8
Costa Rica	10.7	0.5	11.2
Cuba	6.3	0.7	7.0
Honduras	13.1	0.6	13.7
Argentina	3.4	0.3	3.7
Colombia	4.9	0.3	5.2
Turkey	4.6	0.4	5.0
Australia	3.4	0.1	3.5
New Zealand	1.7	0.1	1.8

profound changes would ensue if this commodity were cut out and a 21.6% increase in the dairy production were to be carried through. The surplus situation would almost vanish in such an operation. Few realize that one-third of the present United States broiler production is virtually sea-based. The amount of fish protein in the form of meal and solubles annually going into poultry feedstuffs is approximately equivalent to the total amount of protein presently being produced through broilers. Even in Latin American countries such as Brazil and Chile, it is questionable if the dairy production could be expanded within a reasonable time to the extent required to compensate for the modest amount of protein now provided through seafood.

It has frequently been recommended to Japan to expand the use of milk and vastly to increase its dairy production. Such suggestions are beyond comprehension. This undoubtedly would imply depriving at least thirty million people of their daily food intake. A slightly different situation would present itself if Japan had large unutilized pastures or cellulose-carrying feed that could be effectively utilized no other way than via ruminants. This is not the case. On the contrary, vast pasture areas, the so-called "genya" (1 million acres), are harvested as green manure for the rice fields. The key to the Japanese feeding of their expanding human population (presently 95 million) is the fact that they rely heavily on the sea for supplementary animal protein and leave the soil primarily for insufficient amounts of fat and carbohydrate production and in second place to provide basic plant protein. It is also symptomatic that in order to feed dairy cattle and poultry, as yet rather insignificant in absolute numbers, appreciable sea operations for acquiring protein had to be initiated. Several large-sized factory ships have moved into the Bering Sea with the sole objective of manufacturing fish meal.

From the calculations comparing fish protein with dairy production, Table XV has been prepared in two sections—one covering countries where fish in terms of protein account for more than 15% of the present dairy production and the other with countries below this percentage. In the first case it can justly be maintained that it seems most unlikely that these countries within a reasonable lapse of time could expand their dairy production to such a degree that it could provide the protein quantities that are now being supplied through fish. If all feeding of fish products to livestock were cut out, there still remains a doubt for most countries, with the possible exception of the Netherlands.

2. *Meat Balance*

Table XVI gives selected data indicating the expansion required in each individual country if it were to produce through meat a quantity of protein equal to what now is obtained through fish. It becomes obvious why the Soviet Union attaches so great an importance to the expansion of fisheries. Even with a continued drive in cattle and hog raising, this country appears less likely to be able to provide its people with an amount of protein now procured through fish. A continued pursuit of the present expansion of fisheries undoubtedly offers a more dependable basis for such a raised nutritional standard.

Only in the United States, Denmark, Canada, Switzerland, and possibly in the Netherlands, does it seem likely that through a combined effort of the meat and dairy production it were feasible to compensate for the fish. Outside of the United States and West Europe there are few countries, with the possible exception of Eastern Europe, Brazil, Argentina, and Australia, which would appear likely to manage, through a joint effort of the present milk and meat production, to procure within a reasonable time an amount of protein equivalent to what fish now provides. Analyzing fish in these terms consequently gives a better appreciation of the part that fish is playing in national economies and protein provision. This approach also allows a more valid comparison between agriculture and fisheries and their relative endeavors in the feeding of a country.

3. *Economic Comparisons*

A few words might be added on the economic significance of an increasing switch-over from agriculture to fishery. As far as knowledge and experience go, meat production, and presumably also animal fat production, is cheaper through the seas than by land cultivation. With modern methods of fishing, many types of fish are produced very inexpensively. In modern trawler operations in Atlantic waters one man-year of labor can produce 65,000 lb. of edible fish, compared with the

Table XVI

Fish Balance in Terms of Meat (1957-1958)

(Increase required in present meat production to compensate for fish)

	% Food	% Feed[a]	Total %
India	506.9	35.5	542.4
Ceylon	380.8	19.2	400.0
Portugal	263.7	18.8	282.5
Taiwan	234.1	12.2	246.3
Indonesia	206.8	10.4	217.2
Norway	66.7	140.5	207.2
Philippines	184.3	14.7	199.0
Pakistan	127.3	5.4	132.7
United Kingdom	29.6	45.7	75.3
Spain	62.3	10.4	72.7
Egypt	62.5	3.1	65.6
Netherlands	11.5	52.7	64.2
Morocco	30.1	32.6	62.7
Rhodesia	28.6	32.6	61.2
Peru	53.5	5.4	58.9
Sweden	37.2	20.4	57.6
Greece	53.3	2.4	55.7
West Germany	18.4	29.8	48.2
Belgium	16.4	31.3	47.7
Algeria	45.1	1.8	46.9
Uganda	42.3	4.0	46.3
Ecuador	41.8	3.8	45.6
Venezuela	40.8	3.8	44.6
South Africa	26.4	16.0	42.4
Soviet Union	37.7	3.7	41.4
Turkey	32.2	2.4	34.6
Tanganyika	29.6	3.3	32.9
Finland	24.9	6.7	31.8
Switzerland	8.0	20.3	28.3
Czechoslovakia	17.5	6.3	25.8
United States	8.5	13.9	22.4
Denmark	8.1	13.7	21.8
Canada	13.6	7.0	20.6
Mexico	13.8	0.9	14.7
France	9.8	4.4	14.2
Brazil	9.3	0.4	9.7
Poland	8.2	0.7	8.9
East Germany	6.5	1.8	8.3
New Zealand	2.9	2.8	5.7
Yugoslavia	3.3	1.3	4.6
Australia	3.1	0.1	3.2
Argentina	1.2	0.1	1.3
Hungary	0.9	0.3	1.2

[a] Feed would be represented by meat meal and proteinaceous slaughter waste.

6,500 lb. of beef produced per man-year on the meat-producing farms of the United States. Calculations show that each United States farmer received in the immediate postwar period an annual subsidy of $99, while the fishermen received only $21. The latter also attained a higher annual average income and produced more food, even if the plant products of the farm are included. The average farmer produced annually 34,500 lb. (15 tons) compared to 22 tons by the fishermen (Taylor, 1953). Besides, the fish protein cost in man-hours is about half that of pork in a well-advanced agriculture. This, however, says little about the conversion efficiency, equally important.

The culture of mussels along the French coast dates back to the thirteenth century. Acre for acre, a mussel farm produces 20–30 times as much food as the best pasture land. The French Ministry of Fisheries reported a figure of 10,000 lb. of mussel meat per acre last year as compared with 190 lb. of beef per acre obtainable from the finest pasture (Douglas, 1946).

According to Soviet economic studies, fish culture compares favorably with traditional animal husbandry in the final production of human food (see tabulation).

	Amount of feed (kg.) to produce:[a]		
Food	one kg. live weight	one kg. body protein	1000 kcal. in body weight
Pond carp	4–6	14–25	1.6–2.1
Cattle	9–10	48–53	2.7–3.0
Sheep	9–10	50–55	2.6–2.9
Hogs	4–7	27–47	1.0–1.8
Chicken	5.5–6	28–30	2.8–3.0

[a] Source: Gordon, 1958.

These findings presumably explain the large-scale efforts to expand fish raising in the Soviet Union on a sizable scale. Each farming community is expected to build and run a fish pond to safeguard a cheap local and, in addition, presumably reliable production of high-class protein.

The relationship is not equally advantageous when judged on a calorie basis. The following figures indicate production in million calories per hectare (Mortimer and Hickling, 1954).

Milk	1.8	Eggs	0.5
Hogs (pig)	1.4	Carp	0.4
Butter	0.8	Beef	0.4

This is less relevant, as the protein yield is the decisive factor.

When comparing protein yields of carp with those of plant crops, the outcome is naturally less favorable [as German studies show when applying sewage as manure (Mortimer, 1954)]. Some protein yields (kg./hectare) are: potato, 280; rye, 235; carp, 27.5.

IV. Fish in Improved Nutrition

A. ALTERNATIVE VEHICLES

In many economically and technically underdeveloped regions, local diets are often poor and monotonous, containing a high percentage of such starchy foods as rice, manioc (cassava), maize, millet, sorghum, and plantains. They are poor in quality and unbalanced, with widespread malnutrition as a general result. Protein deficiency is quite common and severe in young children, mainly during weaning. Vitamin shortages are frequently observed. Tropical diseases, severe parasitism due to poor sanitary conditions, and precarious living, all contribute to or add to these deficiencies.

The long-term solution to the problem of protein malnutrition lies in the greater production and better distribution of protein-rich food which can provide a satisfactory and varied diet. In most cases fish offers this in a cheap and attractive form.

It has already been mentioned that various processed products, such as dried fish, pounded to powder or not, canned sardines and other cheap fish packed in cans, fresh-water fish, salted herring, and dried cod have all been instrumental in improving on a broad basis the nutritional standard in many countries and offering a cheap source of high-quality protein. The salted herring and dried cod have been outstanding in history in this respect and still remain the backbone of the low-income diet in the Soviet Union, Europe, Africa, and Latin America. Still, 60% of the imported fish protein in Brazil is represented by bacalão (Borgstrom, 1958). For infant or clinical feeding a more refined product is needed. This partly explains the interest focussed on extracting and providing a fish flour. Prior to this the German war needs had forced the manufacturing of an egg substitute—Viking Eiweiss—through extraction from a whitefish meal (Rudolph, 1946).

B. FISH FLOUR

Fish flour has become an ambiguous designation. It was originally introduced into English to signify fish meal, suitable for human consumption. The French (farine du poisson), Spanish (harina de pescado), and Russian languages (rybnyja muka) all lacked two separate words which could be employed in a distinctive way for this very purpose. These languages therefore resorted to inserting "for human use" each time fish flour in this restricted English sense was used, or rather were forced to stay with the original terminology (FAO, 1958).

Technologically, there was at the same time a gradual slip in the original meaning. The term "fish flour" was not only used to designate fish meal made for human consumption but was also employed for fish protein being concentrated or extracted from whole fish, fish wastes, or fish meal, and finally, when solvents were employed for the extraction, frequently rendering a product both defatted and deodorized. From the nutritive point of view such solvent extraction in most cases meant a narrowing of the value of the product. Fats, minerals, and vitamins were entirely or partially removed in such processing. One advantage is, nevertheless, the likelihood of complete elimination of microorganisms. Such foods were primarily intended for feeding children in the weaning and post-weaning period, but it was hoped that they could be extended at reasonable costs to all markets and made available for the family diet.

For many years the possibilities for developing the fishing industry to provide such protein concentrates have been pointed out. Fish flour is in commercial production in several areas of Africa, including South Africa and Morocco. The United Nations International Children's Emergency Fund (UNICEF) has operated an experimental plant in Chile since 1957. Extraction methods have been developed by the United States (Levin, 1959) and Canada (Guttman and Vandenheuvel, 1957). Indian technologists have used the meal after extracting oil from the oil sardine, and made it into an accepted product (Visweswariah *et al.*, 1960).

In the curing of kwashiorkor, animal proteins such as milk, meat, and eggs, are frequently in very short supply and costly. Fish, especially in the form of industrial preparations of fish flour or similar products, have proved to be less expensive and remarkably effective in infant feeding (Béhar *et al.*, 1958; Gomez *et al.*, 1958).

In trials conducted with children and adults it has been possible to ascertain in several regions which fish varieties prove the most acceptable and what the tolerance level is. The latter is greatly in excess of effective dosage. Fish flour has been used mixed into wheat, rice, millet, peanuts, etc. (see further Chapter 2, Part I, this volume).

1. *Tropical Africa*

In tropical West Africa, fish flour has been added to the basic millet or sorghum diet together with peanut presscake. Such a mixture gave better weight gains than skim milk. The same type of fish-flour-fortified flour was used in the manufacturing of bread given to young men in military camps. Such bread was well accepted (Senecal *et al.*, 1956).

In Uganda, fish flour was manufactured in a pilot plant, an undertaking initiated by the Uganda Fish Marketing Corporation.

Some experiments on the acceptability of various products have been carried out with fish products supplied by the Food and Agriculture Organization. In Senegal and Haute-Volta, a fish autolysate prepared mainly from fresh sardine offal has been tried for dietary improvements. This autolysate was distributed in the form of a paste or dry product to children above 2 years old. In some instances the product was also introduced in the diet of patients recovering from kwashiorkor. The product was very well accepted, and the results on the health and growth curves of the children most favorable. Masseyeff (1956) carried out tests of a different kind, i.e., mere acceptability tests as far as taste and flavor were concerned, among various tribes, and food dishes in the Cameroon. The acceptance records were good among the 4,500 persons in this study. Only one Moslem tribe in Northern Cameroon refused to try the product.

Experiments on infants have been carried out in Dakar under careful medical control. The fish flour used in the tests was prepared from fresh fish fillets under hygienic conditions. The fat content varied from 3 to 8%, according to the fish and the process applied. The quantity given daily varied from 10 to 50 g. A sauce resembling nuoc-mam, but manufactured from indigenous fish resources in Dakar also gave good results (Toury *et al.*, 1958).

Protein deficiency is also the chief problem facing Ghana (Mayer, 1959). The supply of fish, although mostly from the ocean, is highly seasonal; for about 5 months of the year the fish come down to shoals for spawning. Dried fish is distributed as a powder, which is eaten not infrequently but in too small quantities.

A fish, "ndagala" (*Stolothrissa tanganicae* and *Limnothrissa miodon*), from Lake Tanganyika can easily be made into a dehydrated powder. Such a product has tentatively been introduced into Ruandi-Urundi (Roels, 1956). Small fish (about 3 cm.) have a protein content of 13%, and large specimens (8 cm.) 18%. The fat percentage varies with species, season, age, and size in the range of 7.6–0.8%. High fat content reduces the shelf-life of the dried product. The "ndagali" is also a good source of vitamin A. The powder is incorporated into soups and sauces. The reception has been encouraging. This dehydrated fish powder with 72% protein is the most hygienic and most economical way of making fish available to poor inhabitants living at fairly long distances from the lake (Roels, 1956).

In Cameroon, fish cultivation has also been employed with a fair amount of success. Two *Tilapia* (*T. melanopleura* and *T. machocheir*) were introduced in 1948-1950, and several thousand family ponds for their cultivation have been built (Bard, 1956). The number of privately owned *Tilapia* ponds has grown from almost nothing in 1951 to above 5,500 covering 211 hectares.

The flesh of *Tilapia,* in the nutritive value of its protein, is quite comparable to that of mutton or pork (Couvreur and Maes, 1956). Lysine and histidine are particularly abundant. The flesh is greatly appreciated by the indigenous population.

2. *South Africa*

The South African Fish Research Institute developed in 1958 a commercially adaptable process for the production of neutral fish flour from cheap and oily fish, such as pilchard, maasbanker or horse mackerel. This flour had a protein content of 75–80%, with a biological value matching that of good quality unprocessed fish meal, viz., ± 86. This refined flour could readily be incorporated into brown bread without imparting foreign flavors or odor. It also could be employed as an improver of the dough, and rendered a pleasing golden sheen to the finished loaf. In this manner a cereal protein (± 11%) in the bread was supplemented with about 5.6% of good quality protein, thus yielding a protein enrichment of more than ± 50, while about one-third of the total protein was of animal origin (Lategan, 1956).

3. *Europe and Morocco*

Fish meal is manufactured for human use in Spain to be employed in various fish soups. The Moroccan fish industry reports the successful manufacturing of a tasteless fish flour made from small-sized fishes. Herrera (1959) has studied the economic feasibility of creating a series of such fish-flour plants along the coasts of the Mediterranean in order to utilize the large amount of such small-sized fish available in these waters.

Such a sardine product is manufactured in Morocco. This was officially approved for use in school lunches, infant hospitals and food centers for the poor. Protein deficiency incidences have largely disappeared due to these measures.

C. FISH MACARONI

A fish macaroni with a good shelf life has been developed by the Mysore Institute of India. Within four hours after catch, minced iced fish of "gende" (*Barbus carnaticus*) is blended with an equal amount of tapioca flour. The product is made by partial gelatinization of part of the tapioca with hot water, adding wheat semolina, extruding the paste and drying. Sorghum flour can replace that of tapioca. This product can be spiced by adding salt (2%), chillies (1.2%), and tamarind extract, which give it a better keeping quality. Such fish macaroni are cheap and can be manufactured in the home (Bhatia *et al.*, 1960).

D. FISH BISCUITS

In Morocco and Chile, it has been tried with considerable success to incorporate fish flour in biscuits. The baking heat must, nevertheless, not be allowed to impair the nutritive value of the fish protein (Miller, 1956).

E. DRIED (DEHYDRATED) FISH

Fish in dried and salted form has unquestionably played a tremendous role in human history (Webster, 1959). Since earliest times the dried fish of Europe (Norway, Rome, etc.) in the form of bacalao has found its way as a precious cheap animal protein into both the African and the Latin American continent. This is also true of the Caribbean islands, since they depleted their natural protein riches in the form of the green turtle. Still today many tens of millions of the human race avert protein deficiency through the lowly dried fish from distant waters. Canada has now joined the supplying nations.

It is worth mentioning that dried cod or any nonfatty or extracted dried fish represents the most potent protein commodity on the scene of world trade. The figures in the tabulation below show that it surpasses dehydrated milk by a wide margin in this respect. As to load unit, it carries 2.5 times the protein contained in nonfat milk solids. It is eminently well suited for relief purposes and subsistence on a trade basis.

	Water (%)	Calories (100 g.)	Protein (%)	Fat (%)	Carbohydrate (%)	Ash (%)
Dried cod	12.3	375	81.8	2.8	trace	7
Solids	—	428	93.4	3.2	trace	8
Nonfat milk solids						
Dehydrated skim milk	3.5	362	35.6	1.6	52.0	7.9
Solids	—	376	36.9	1.7	53.9	8.2

Dried salted fish plays a dominant role in the diet of the indigenous population of Angola. Its nutritive value has been studied and found excellent (Saraiva da Costa, 1956; Adrian *et al.*, 1956). Some variation is in evidence with regard to tryptophan. Whether this is due to poorly controlled conditions for drying of the fish or reflects analytical uncertainties is still an open question.

F. Fish Sausages

Since long ago Japan has broadened the use of fish by developing a series of specialized products and dishes—soups, jellies, and stuffed algae. The latest innovation, namely, fish sausages, seems to become the leading item in this galaxy of fish products. Unquestionably the formulation of such a wide array has a direct bearing on consumption.

Fish sausages have been marketed in many countries for a number of decades, in Germany, Poland, the Soviet Union, and occasionally also in the United States. There are numerous reasons why they have largely failed to create a food market. Only in Japan and possibly the Soviet Union have they become the basis of major commercial manufacturing. Even in the United States various types of tuna sausages are gradually making inroads. The Japanese fish sausage industry is a product of the 1950's and now reaches an annual output exceeding 150,000 metric tons. All the range of ordinary type meat sausages are available, e.g., frankfurters, bologna, and salami. In world feeding, this development is most significant. Already more fish protein is channeled through this single item than through fish flour. Alongside dried fish, it appears likely that fish sausages or similar ready-to-eat foods have greater potentialities as a vehicle for cheap fish protein than more elaborate fish proteins. The need for adding preservatives is a limitation, but not a decisive one. Dried salami-type sausages constitute good alternatives. One advantage is the full use of all dark meat, flesh from less accepted species, as well as whale meat, which thus find their place in the feeding of human beings.

G. Better Utilization

1. *Processing in General*

The previous section brings into mind the obvious fact that the better the seasonal gluts and distant catches can be saved from spoilage and ultimate destruction, the greater are the resources available for efficient feeding of man and animals. In a primitive economy and distribution fish, of all commonly available foods, presumably suffers most because of its high degree of perishability. This might be considered a liability, but, on the other hand, investments in this sector become more urgent and pay off more conspicuously. Dried or salted fish and sauces were an early response to this challenge. Modern methods have all made their impact—canned tuna and salmon, freezing of bulk fish (tuna, sardines, fillets, etc.), and salted herring, all carry evidence to the tremendous expansion of fish use in both time and space (see further Chapter 19 of this volume). The growing number of floating factories now operating in almost all oceans depend in their usefulness on efficient processing methods.

2. *Floating Processing Units*

The long-distance fishing now being developed by a growing number of fishing nations and combined with on-the-spot processing through freezing trawlers, floating canning factories, or mother ships is an important new feature in world fishing. The consequences of utilization will be discussed in Chapter 19 of this volume and as to the expansion of the feeding basis of various countries in Chapter 21 of Volume III.

Here it may suffice to say that this new trend already has had a substantial effect of broadening the position of fish in the national diet of many countries. This applies particularly to the Soviet Union (Borgstrom, 1961b) and Japan, and in the immediate future, to China, Poland, and West Germany also. Japan is fishing extensively in the Mediterranean, Southwest Atlantic, and off the Canaries. Freezing plants are contemplated at Las Palmas for re-exporting to Japan.

3. *Use of Wastes*

Under the pressure of their needs, a number of countries have developed methods to save some of the nutritional riches now wasted. Economy has also been a driving force in this unmistakable trend. Rewarding results are reported from the shrimp industry. Parts of the fish meal industry, as well as the entire manufacture of fish solubles, constitute major contributions to saving much of what earlier was either discarded on board or in plants, or lost in stickwater (see further Chapter 19, this volume).

H. GLOBAL REQUIREMENTS

1. *The Population Upsurge*

In the brief period since 1945 the world's population has increased by a number equivalent to 3 times the present United States population, totaling 600 million. In a number of countries the population doubles in 25 to 30 years, and the world's in less than 40 years.

This mounting number of human beings is not caused primarily by any unexpected increase in birth rates. On the contrary, almost all countries, with the exception of the United States, are showing drastic declines. The upsurge is almost entirely due to an appreciable reduction in infant and child mortality.

Statisticians predict, nevertheless, that even with an expected slackening of the increase in world population at least 3 billion additional people have to find their living in this very century. Asia, in 50 years from now, will be almost as large as the entire world population today. It is consequently becoming increasingly difficult to feed the world.

The world desperately needs proteins—and at a cheap price level. This is a tremendous challenge to fisheries all around the globe.

2. *Perspectives*

Nevertheless, in most discussions and studies of these matters, the magnitude of the feeding task facing mankind is underestimated. Even the fisheries become pygmean in the light of the present requirements, not to speak of the rate at which they too are multiplying.

In latter years the annual net growth of the human population amounts approximately to 55 million. In order to provide merely this yearly additional human load with animal protein from the seas and on the United States standard, the present world catch would have to be almost doubled each second year! If these annual newcomers were satisfied with the more modest Japanese standard the total world catch would have to be doubled each tenth year. And yet nothing would thus be done to alleviate the present grave shortages already prevailing in several crucial areas (see Fig. 1).

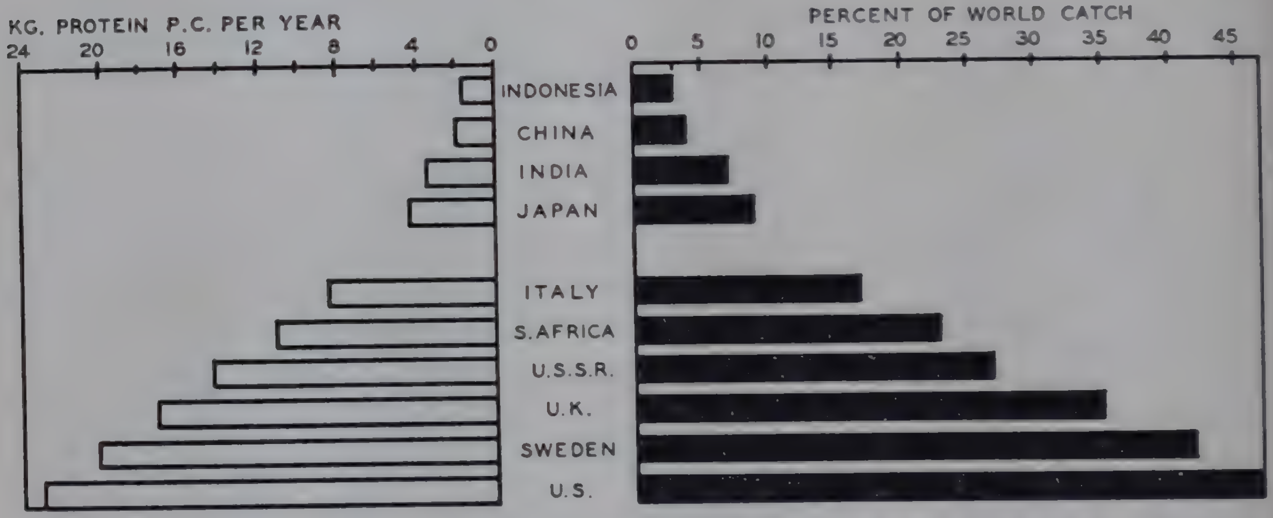

FIG. 1. Expansion required in present world catch of fish to feed the present annual increase of world population (55 million)—right hand section—at different levels of protein intake (left section).

If present-day China were to improve its nutritional standards enough to enjoy the Japanese diet, this one requirement alone would necessitate a doubling of the present world catch. Yet the entire ocean harvest would have to be earmarked to meet the needs of this single nation. A Soviet standard would raise this figure to four times the entire world catch, and this to satisfy only China.

Today the United States through meat alone is consuming almost as much protein as is totally available in the world's entire catch of food fish (see Fig. 2). The resources of the sea are definitely minor when measured against the needs of the oversized human race. Our only recourse seems to be an organized farming of the seas, but this necessitates a tremendously expanded program for oceanographic and fisheries research. Man's conquest of the seas is infinitely more urgent than probing into the universe. The billions now squandered in the space race would have given mankind a more solid and dependable basis for cultivating the oceans. We are now largely lacking the basic information required for such a tremendous endeavor.

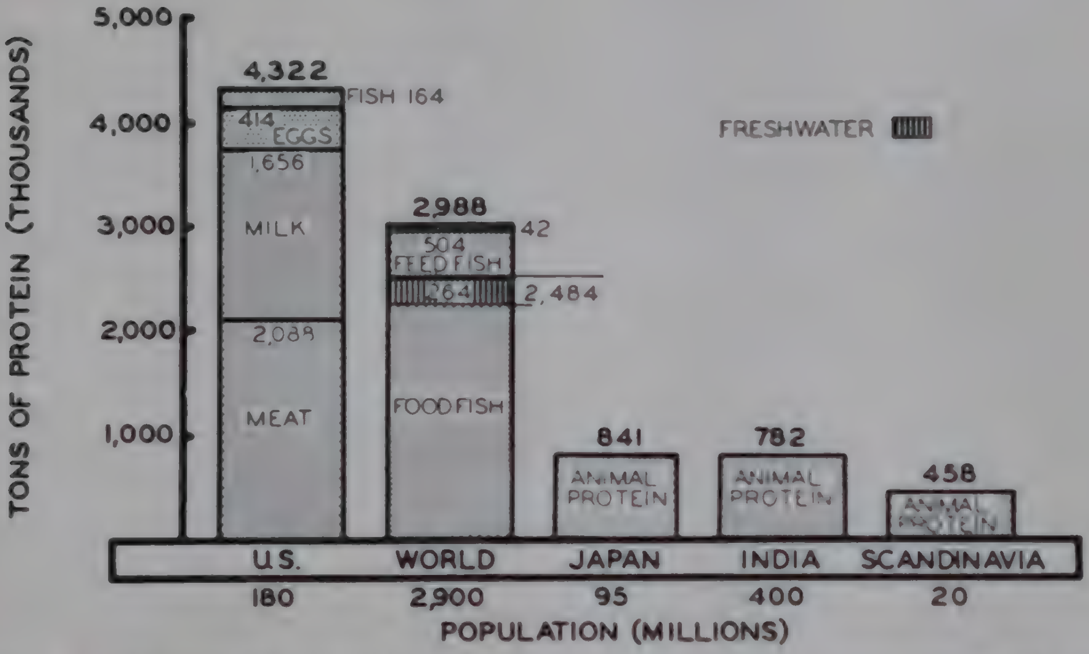

FIG. 2. Fish protein in world catch compared to present consumption of animal protein in selected countries.

Another way of relating sea harvests to nutritional needs is to pose the question: What additional catches would be required to improve the low and frequently inadequate standard of the less-well-fed countries. Table XVII lists some selected cases. They all underline the substantially greater harvests that would be needed and the smallness of the ocean when measured against the human giant. Wise utilization and

TABLE XVII

PERCENTAGE INCREASE IN THE WORLD FISH CATCH REQUIRED FOR NUTRITIONAL IMPROVEMENT

Country (and population in millions)	Increase (%) required to meet nutritional level of:			
	Japan	Soviet Union	United Kingdom	United States
China (655)	63	193	310	473
Japan (95)	—	18	34	59
Indonesia (90)	14	31	44	59
Mexico (33)	—	—	12	20
Philippines (24)	—	6	—	17[a]
Taiwan (10)	—	3	—	7

[a] New Zealand level.

TABLE XVIII

INCREASE IN WORLD FISH CATCH REQUIRED TO IMPROVE PRESENT AVERAGE NUTRITIONAL STATUS OF ENTIRE LIVING WORLD POPULATION[a]

Calculated against the animal protein level of the following countries	Grams per day per capita	Increase required in the daily intake (grams per capita)	Additional amount of protein required (1000 metric tons)	Increase in present world catch on the assumption that:	
				All improvements are through fish	The present ratio (13.1%) between fish and other animal food products is retained
Soviet Union	33.0	10.8	11,826	3.9	0.52
United Kingdom	46.8	24.6	26,937	9.0	1.18
United States	66.0	43.8	47,961	16.0	2.10

[a] Present level of average animal protein intake per capita world inhabitant: 22.2 g. per day. World population: 3000 million.

intelligent adjustment appear highly advisable in order to cope with mounting human distress and enable mankind to enjoy the riches of the sea. Table XVIII shows the magnitude of the changes required to improve the over-all nutritional standard of the world under two basic assumptions: either all betterment would come through fish or the present ratio between fish and other animal protein be maintained.

I. Upgrading of Fish Meal

Enormous as human needs may appear in relation to the aquatic harvests, present and prospective, essential improvements could be accomplished by upgrading the one-fifth of this catch that is now used to feed poultry and other livestock. Employing these resources on a global scale directly for human beings would have notable marginal effects.

If one accepts the nutritional level now prevailing in each individual country as a standard, the fish protein presently going into feedstuffs would, if used directly, feed approximately 400 million people on a Japanese level of animal protein intake. If employed in filling the needs of the undernourished of the world, it could be stretched to meet the requirements of more than a quarter billion (see accompanying tabulation). This could include still more millions if other traditional sources of animal protein could contribute their part. It should, however, be recognized that around one-fourth of this quantity constitutes true waste-utilization and presumably could only partially be converted into suitable human food.

Protein in Fish Meals and Solubles if Used Directly for Human Feeding (1960)

Area	Animal protein intake		Population that could be fed (millions)	
	Grams per day	Kilograms per year	I[a]	II[b]
East Indies	6.6	2.4	330	250
Japan	17.4	6.4	123	94
Italy	25.9	9.5	83	63.5
Soviet Union	33.0	12.0	66	50
United Kingdom	46.8	15.3	51.5	39
United States	66.0	24.1	32.5	25

[a] I. Approximate amount of fish protein in all products not directly consumed as human food (790,000 metric tons).

[b] II. Approximate amount of fish protein made into fish meal and fish solubles from whole fish (not wastes, etc.) (600,000 metric tons).

Most of the fish meal now manufactured from whole fish ends up in the markets of well-fed nations (see Fig. 3). A debatable fact is that this protein is provided by the two major protein-starved areas of tropical Africa and Latin America. No less than one-sixth of the protein extracted from the Pacific in this way moves to feeding the livestock of North America (⅓) and Western Europe (⅔). This general picture has become still more accentuated in later years (1959–61). See further chapter 19, this volume. This protein in the form of dried fish or even fish flour would make the animal protein level of the Andean region surpass that of Western Europe and raise that of the entire Latin American continent to Mediterranean standard—see further Borgstrom (1958).

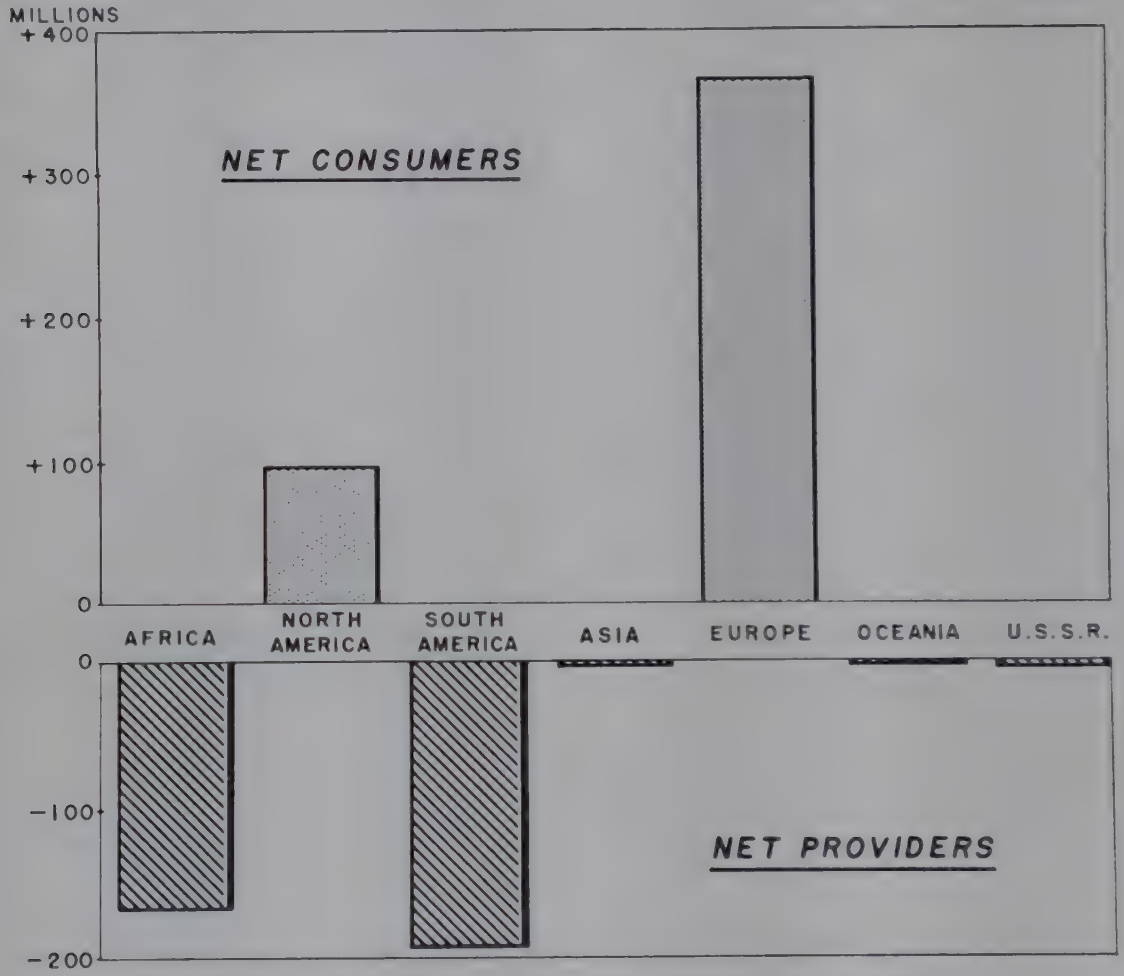

FIG. 3. Net result of fish protein transfer via fish meal.

V. Potentialities

A. FISH AND SHELLFISH POTENTIAL

The Food and Agriculture Organization estimates in 1961 that the yields of food from the waters of the world could be doubled without endangering the stocks (Finn, 1960). Since 1953 the catch increase has exceeded 27%, and this rate of expansion in fisheries may be expected to persist (Morgan, 1956; Walford, 1958). This will be accomplished by: (a) more efficient fishing of persistent stocks, (b) exploiting of new species, (c) moving downward in the production pyramid, (d) fishing in new areas, and (e) expanded cultivation (see also Merriman, 1950; Cushing, 1959).

There are many fishery resources not fully exploited and many others that have not been worked at all. Not more than 10% of the world's flatfish resources are at present being utilized (Walford, 1958). Examples of very rapid expansion in recent years are the South African pilchard fishery, the saury fishing north of Japan, the tuna fishery which has been developed in the South Atlantic from both the African and the South American shores, new shrimp fisheries in the Caribbean, the Mediterranean and other waters, sardine fisheries off tropical Africa and that of the Peruvian anchovy. In Australia, a crayfish fishery has been opened in the West and a prawn fishery in the East. New scallop banks are being exploited off Florida (Lenier, 1959; Maurin, 1959).

We are at the starting point of the fish exploitation of the southern seas. The Guano Islands outside South Africa are the proof of the immense resources which can be utilized. In a few days here more fish than the entire world catch is caught by birds. Off Madras in India, scientific surveys show that only 5% of what could be utilized without risk is now taken ashore. The Humboldt Stream off the Pacific coast of South America carries immense values. But extended scientific surveys are needed and the economic feasibility especially has to be studied. A coordinated effort is made by the United Nations Economic, Social and Cultural Organization in a multination research program to establish the potentialities of the Indian Ocean.

1. *Increased Yields*

A number of variables, intricately interwoven, determine the ultimate yield and thus the catch basis of ocean regions; such variables are seasonal changes, meteorological conditions, hydrographic characteristics, bacteriological and biochemical activities, and the biological balance. Some of these interrelationships are analyzed by Hempel in Volume I, Chapter 1 (see also Carruthers, 1956; Cushing, 1959).

Fishing efficiency is evidently intimately related to methods of capture. Modern fishing has undoubtedly been aided by important new devices, e.g., the echo-sounder. This device alone has served to bring about a vast increase in the catch of Pacific herring, for example. To be sure, it has replaced a more time-consuming method. It has made fishing more mechanical, and at times it has made possible the detection of herring that might otherwise have escaped the fishermen. But it has not, single-handed, brought about an increase in the catch of any significant order of magnitude (Boie, 1960).

Submarine studies of fish behavior, such as those conducted by the

Soviet bathyscape *Severyanka,* establishing how shoals and individual fishes react when facing nets and trawls, are invaluable in improving equipment and catching methods. One major problem seems to be the development of nets for the catching of pelagic fishes in high sea operations. Various devices are now under trial for such depth fishing (see von Brandt, 1960).

Some figures of present catches show the great discrepancies between different waters, as set forth in the following tabulation:

	kg./hectare		kg./hectare
Waddenzee[a] (Holland)	200	North Sea	26
Hoffden (mouth of the Thames)	52	English Channel	28
		Kattegat (Skagerrak)	27

[a] Catch of flatfish, herring, shrimp, and mussels.

In most cases these figures reflect the basic productivity of respective waters, as fishing in the listed areas is highly developed. Climate, as manifested in temperature, is the most decisive factor in primary production and also in fish outtake.

Carp ponds under favorable conditions may give an annual yield of 300 kg./hectare (see Section V, B, 1).

The following factors are limiting and govern ocean productivity as they determine the level of the primary phytoplankton crops: (a) supply of nutrient salts, (b) light, (c) temperature, and (d) grazing by animal organisms. The relative importance of these conditions differs from season to season and is dependent on cloudiness, day length (latitude), outflow of rivers, runoff from land, etc. Seasonal variations are naturally most noticeable in temperate regions.

On bright days during midwinter, a rate of organic production per unit area of about 20% of that encountered on sunny days during summer was measured in Danish water (Steemann-Nielsen, 1953). On dark days with heavy rains, the light intensity may be only one-tenth that on a normal clear day. But only then does a slight reduction of the photosynthetic rate take place at the surface.

Fertilizing, either through rivers loaded with mineral salts or through runoff from land areas into coastal areas, affects fish yields. Numerous examples of such localized effects are reported from many areas, for example, the mouth of the Thames, conveying per year 3,000 metric tons of phosphate-phosphorus, thus doubling the fish yields in the mouth area in comparison to average catch figures in the English Channel and the northern North Sea. Fish catches at Lofoten, in coastal waters off Southern Norway, in the Atlantic off the Iberian peninsula, and in California follow closely the amount of precipitation on adjacent land areas. Production is determined by availability of not only NPK but also trace elements and, interestingly enough, in a few cases also such minor compounds as B_{12} (Erikson, 1952).

As a consequence, the great fishing waters of the world are located where mineral-rich waters well up from the depths, glaciers exert a fertilizing action, runoff carries mineral nutrients into the water, or there is turbulent mixing of waters belonging to different currents. In such localities the world's great fisheries thrive.

Little replenishment of nutrients takes place from below in tropical areas, and plankton production is poor except in areas of upwelling or seasonal runoff (monsoon regions, etc.) (Steemann-Nielsen and Jensen, 1957).

Artificially induced upwelling of nutrient-rich bottom waters has been proposed as a means of obtaining higher marine yields. In order to be effective, great volumes of water would be involved, whether mostly through pipelines or natural circulation. A tremendous amount of heat would be needed—approximately 5.6 million tons of coal per cubic mile of water. In effect it would cost more to raise one cubic mile of water 1°C. than the present energy value of the entire world catch.

Direct fertilizing is another proposition. In limited areas this could undoubtedly be accomplished, but on the vast expanses of open sea this would be grossly uneconomical (Cooper, 1948). Besides this, the biological balance effects may in the long run not favor what man wishes to use. Also we soon reach a dangerous upper limit for primary production frequently resulting in mass kills of fish (see below).

At the present stage, direct fertilizing of the oceans cannot be expected to give a reasonable return or produce any reliable result. Farmers do not apply fertilizers blindly, but to arable land and to soils needing it, and in quantities adjusted to specific requirements—this is an economically rational procedure. As ocean productivity depends largely on the degree of survival in each year-class, it appears most attractive to provide the spawning grounds when necessary with additional nutrients to build up or guarantee availability of food. Such a proposition, however, requires extensive further study to allow better understanding of the basic mechanisms and the dependability of the effect on the ultimate fish yield.

Coastal fisheries are in most countries being supplemented with motorized vessels for more distant fisheries, employing larger craft and more efficient catching gear. In the archipelagoes of the Southern Pacific the inshore reefs and lagoons are all becoming seriously overfished, and even for subsistence, fishing now has to turn to deeper and more distant waters.

2. *Oxygen Deficiency*

In many regions of the world the oxygen balance of the water determines its productivity. In warmer regions and during hot periods of temperate regions a thermocline may be created which becomes a barrier for free transfer of oxygen. Deeper layers become depleted of oxygen and major fish kills result, such being reported from the Walvis Bay off South Africa (Copenhagen, 1958) and from the Chesapeake Bay (Anonymous, 1959).

Water blooms induced by surface runoff in monsoon periods may also upset the natural balance between oxygen consumption and production and cause disastrous mass kills of fish.

3. *The Scattering Layer*

During the war a scattering layer was observed some 400–600 feet below the surface, with a diurnal movement, upward during the night and downward again with dawn. Several animal groups have been proposed as responsible; euphausids and other shrimp-like microplankton, squid and small fish, possibly bathy-pelagic—see further a review by Hershe *et al.* (1952).

It is still an open question whether this layer constitutes a new untapped source of food or these accumulations of marine animals already are efficient links in the present food production chains. Recent observations by the German research vessel *von Dohrn* point to the possibility of several scattering layers, at varrying depths. Some may be explained by salt and temperature gradients conducive to fish accumulation (see von Brandt, 1960). Whatever the source of such layers, it must be borne in mind that they ultimately rely on the primary production of the photic zone. A new alternative has, however, emerged with the discovery of dark-living organisms capable of utilizing carbon dioxide.

4. *Overfishing*

It is a common fallacy that present yields of major fishes constitute only an inconsiderable proportion of the total stock in the sea. For such fish as the plaice, cod, and haddock of the North Sea, the catch in this country has attained approximately 70% of the fishable stock (Graham, 1944).

The Northern Hemisphere in several regions, especially along the continental shelves, is facing overfishing problems. This situation is aggravated due to the mounting population pressure. The North Sea catches after each of the major wars increased markedly but subsequently were followed by a decline, with serious repercussions in both cases.

This drop in the fish population shows up first with demersal varieties, e.g., haddock.

In spite of a growing recognition of the need for regulating the commercial fisheries, and for improving techniques of management, depletion of marine fisheries has continued. In only a few cases have international conventions been effective, as, e.g., for the Pacific halibut. Some species have been exploited to the vanishing point as, for example, Atlantic salmon and sturgeon. The yields of other species, such as shad and oysters, have been impaired, and little has been done to correct the situation.

Japan is also encountering the ominous specter of destructive overfishing. The number of fishermen and boats has increased to the point where the catch per fisherman in nearby waters has been seriously reduced.

The true nature of the decline in sardine availability along the shores of Yeso and Korea in 1929, outside California in 1942 and on the Atlantic coast of the Pyrenean peninsula in 1945 has not yet been revealed. Oceanographers and biologists are jointly tackling this problem. But it does seem reasonable to surmise that one factor leading up to this effect has been the extensive utilization of these resources. The economic repercussions, in any case, have been serious.

Fishing for ocean perch has been very heavy in recent years, and the abundance of this fish has been gradually reduced along the United States Atlantic coast. Fishing vessels are now obliged to travel great distances to obtain commercial quantities, sometimes up to 500 to 600 miles from port, while earlier the bulk was caught within 150 miles.

Depletion signs have, however, turned up in several regions. In Australia it is necessary now to take stock of the shark resources. The stock of many favored Australian fishes, such as mullet, bram, and flathead, are already depleted, which is the chief reason for the expanding catch of barracuda. A critical factor on the Australian scene is the low water runoff from this continent, meaning minor additions of mineral nutrients to coastal waters.

5. *Removal of Competition*

One way of broadening man's sphere in the ocean and procuring more food is an extended elimination of major competitors. Starfish and other invertebrates, feeding on the same organisms as do major food fishes in Danish waters, leave only 1–2% to man. The bottom fauna of the Kattegat is estimated to weigh 7.5 million metric tons. Investigations show that no less than 6 million tons of this biomass is consumed by animals not rendering useful food to man. As much as nine-tenths of the production of the seas is estimated never to enter the production cycles from which man is harvesting.

One single starfish species in the North Sea consumes so much food that its removal would allow a doubling of the present plaice stock. All these invertebrates can be likened to weeds in fields and gardens. If enough of them could be removed—e.g., to allow man's food fish to increase ten times more than at present—our hauls in the fish catch in a given area would increase correspondingly. The question remains: Can such a major encroachment by man take place without serious deleterious disturbances in the sea's balance of life?

As early as the nineteenth century, radical measures were taken in many fishing areas of the globe against the competitors of man: bears, fur seals, sea birds, starfish, urchins, etc. Soviet scientists have studied the toll taken by various fish-eating birds in major internal waters and recommended regular eradication in their populations (Pachuljskij, 1957).

One group of competitors is the predators. The fur seal catch is twenty-two times the weight of all the salmon caught in central and western Alaska during 1958. This is an approximate estimate which only shows the magnitude of the toll taken by these animals. The colonies on the Pribilof Islands consume annually more fish than the combined total weight of fish landed each year by the entire North American Pacific coast fishery. Although ordinary seals catch more, they are not in serious competition as they eat chiefly deep-sea fish.

There is quite some disagreement as to the effect of seals. Soviet scientists belittle the role of fur seals as predators, while the Japanese contend that considerable damage can be attributed to them. There is also sharp diversity of opinion as to the toll taken by gray seals in Scottish salmon waters. The catch of pelagic species is only minor compared to the take of predators. It is reported from the Black Sea that dolphins consume 50 kg. per hectare per day (Vodianitsky, 1958).

6. *Primary Production*

The categories of production of seas and lakes are given in the accompanying outline; the categories are grouped in very broad terms, considering chiefly economically important species (left column).

The most recent estimate of the average annual net primary production of the oceans arrives at a figure of 1.2—1.5 × 10^{10} tons of carbon (Steemann-Nielsen, 1960). This in terms of net amount of living phytoplankton is about 50 × 10^{10} tons. The assimilation is a more reliable indicator of total production than plankton sampling, as it is gradually becoming more evident that nannoplankton constitutes a major portion of this primary production, particularly in tropical waters (Holmes, 1961; Wood, 1961). On the basis of the above indicated figures, the following average figures can be calculated for each production level (in million metric tons of product weight): primary production (phytoplankton), 500,000; secondary production (herbivores), 100,000; primary carnivores, 10,000; secondary carnivores, 1,000.

Outline of Aquatic Production Levels

Groups of econ. importance	Major categories
1. Primary producers	
Diatoms	Protozoans
Dinoflagellates	Phytoplankton, including nannoplankton
2. Secondary producers (herbivores or grazers)	
Menhaden	Zooplankton
Atlantic sardine	
3. Primary carnivores	
Blue whale, humpback whale	Fish
Finwhale	Whales
Salmon, whiting, smelt	Invertebrates, including squid
Herring, sand eel	
Ciscoes, lake herring	
Oysters, shrimp, squid	
4. Secondary carnivores	
Mackerel, flounder	Fish
Salmon	Rorqual, porpoise
Saurel	
Sperm whales	Starfish
Squid	Birds
5. Tertiary carnivores	
Tuna, plaice	Fish
Halibut, haddock	Sharks
Dolphins, seals	Bears
6. Quaternary carnivores	
Cod, swordfish	Fish
Pike, lake trout	Sharks
Killer whale	

This is under the assumption that the organisms which compose the life on these levels are equivalent. This is not the case. An upgrading whereby key substances become concentrated takes place. This is evident from the composition of phytoplankton relative to fish (see tabulation).

Consequently, the billion metric tons of secondary carnivores have to be modified. A reasonable minimum correction factor would be 2.4, giving a value of about 420 million metric tons. This includes many other marine animals besides fish and many fish not utilized as human food. It is generally estimated that the fish in the food category cover around one-tenth of the marine life. So far the theoretical reasoning has been based on a complete energy transfer, which is highly unlikely.

Finally, it is inconceivable in any single year to tax the stock entirely. This is impossible under practical conditions. A reasonable percentage will have to be left for future growth.

Constituent	Phytoplankton (%)	Fish (%)	Ratio
Water	90	76	—
Dry solids	10	24	2.4
Carbon	4.4	12.8	2.9
Energy	[a]	3.6[a]	3.6
Protein	2–3	18	6–9
Nitrogen	0.5	3	6
Phosphorus	0.11	0.95	8.6

[a] Source: Calculated by the author from various analytical data.

At the other end of the balance is the fact that some important food fishes are primary carnivores, e.g., herring, while a few, such as menhaden and sardine, are herbivores. Most codfish, on the other hand, require 4 to 5 links. Whichever conclusion one reaches on all these crucial points, it is evident that the available harvests from the oceans are limited and at the most could be one order higher (ten times) than the present catch of 39 million metric tons. It must be assumed that a certain feedback takes place at each level, the magnitude of which we know very little. Wise economizing and efficient utilization are, consequently, imperative. (For further discussion of the primary productivity of the oceans see Riley, 1944, and Ryther, 1959.)

Man's food from the sea also emerges as an impressive force in nature when the total fish catch is matched with the total photosynthesis of the oceans—see Table XIX.

The figures for primary production of the oceans are obtained under the assumption of three conversion links and the aquatic consumption being totally 1% of the total calorie intake of mankind. Even here it must be true that some energy losses take place. Presumably not all energy assimilated in the oceans is utilizable in man's production cycle. Consequently, it seems safe to say that man is already indirectly disposing of at least 10% of the ocean's total primary production, but this figure increases 1.7% each year, due to the net increase of world population, and an additional 5% due to the yearly expanded world catch—i.e., almost a doubling in each decade in the period immediately ahead.

Against the background of these figures, it is easier to understand that the present North Atlantic catch, when compared to the measured photosynthesis of these waters, allows only three conversion steps (3.14) counted from the primary production. As for the heavily exploited stocks of such fish as plaice, cod and haddock, man is, on the average, disposing of no less than 70% of the fishable production in the North Sea.

The herring catches landed in Europe exceed 2.5 million metric tons. Their feed calculated in original phytoplankton is equivalent to 30.5 million metric tons of wheat—i.e., approximately the United States wheat crop, 1.5 times that of Europe, or one-eighth of the world's total wheat crop.

Table XIX
Man's Food and Total Photosynthesis[a]

	Total		Land		Sea	
	kcal.	%	kcal.	%	kcal.	%
Kilocalories $\times 10^{14}$	4350 (5000[b])	—	850 (1500[b])	—	3500	—
Primary calories	307.5	7.1	157.5	18.5	150	4.3
Direct consumption	26.3	0.6	26.0	3.1	0.3	0.09

3 billion people × 2400 calories per capita per day = 26.3×10^{14} kcal.
Livestock representing about 13.8 billion people = 131.2×10^{14} kcal.
157.5×10^{14} kcal.

[a] Source: Cole, 1958; Borgstrom, 1962b.

[b] Only half metabolizable directly as human food; ruminants use approximately 100×10^{14} kcal. of this.

The Danish biologist Petersen (1918) proved for cod that 100,000 kg. of plankton and eel grass are required to provide 1 kg. of codfish. Even if several other codfish, such as haddock, saithe, and pollock, may reach adult stage in four conversion links, the total plant production in the sea required for the world's codfish corresponds to about 22 world wheat crops (Rudolph, 1946).

One unsolved question is to what degree nonliving organic matter of the seas can serve as food. Obviously, the matter is not renewable, but may for some time constitute a reserve, allowing more carbon and nitrogen to get into circulation within living matter. Fox *et al.* (1956) give some values for this reserve (see tabulation).

	Number of cells per liter (in 1,000)	Weight of individual cells (mg.)	mg./liter
Dinoflagellates	10	2×10^{-5}	0.2
Diatoms	20	1.5×10^{-6}	0.03
Bacteria	45,000	5×10^{-11}	0.002
Total (living matter in primary production)			0.232
Nonliving organic matter (part of leptopel)			5–15

Consequently, it can be inferred that there is some 20–60 times more nonliving organic matter available in sea water as compared to what is built into living cells.

7. *Nitrogen Fixation*

To the primary production of the oceans the availability of nitrogen is equally important. In spite of this element being indispensable to protein production, little is known of nitrogen fixation at sea. It appears unlikely that the runoff from the continents and already available nitrogen would provide a sufficient basis for a maintained production of living matter, particularly in view of the extensive denitrification going on in many areas. Recent findings point to the existence of nitrogen-fixing microorganisms (Allen, 1961). This vital sector of mankind's crucial nitrogen and protein front certainly deserves far greater attention than hitherto.

8. *Fresh Waters*

The conversion of the primary photosynthetic production of lakes into fish and other food used by human beings basically follows the pattern of the seas (Ohle, 1955; Hutchinson, 1957). Latitude, seasons, soil conditions, climate, and pollution naturally exert a more profound effect on productivity than in the oceans. In general, there are fewer conversion links. A good idea of the relationship may be had from the annual production of crude protein (see tabulation below) established by Juday for Lake Mendota (Wisconsin).

	kg./hectare		kg./hectare
Phytoplankton	2,501	Bottom fauna	33
Rooted plants	64	Fish	3.4
Zooplankton	203		

9. *Farming of the Sea*

Taking food from the sea today is still largely a matter of hunting. Aquaculture in the ocean is largely in the realm of science fiction. Such a venture would be infinitely more complex than any other form of agriculture. To develop ocean farming on a scale large enough to make a meaningful contribution to the world's food supplies is an undertaking requiring comprehensive and fundamental research of immense scope (see further Southward, 1960).

The primitive aquaculture which has emerged through the centuries is fish farming, shellfish raising and seaweed cultivation. In protected waters, such as bays, estuaries, swamps and lagoons, water organisms have been raised ever since antiquity—and on a constantly enlarged scale. Nevertheless, to take the step of leaving direct land contact and plunging into the real oceans to develop full-fledged sea farming is a tremendous endeavor.

In simple enclosures with natural production, even without feeding or fertilizing, half as much animal protein can be produced as on average farmland. By carefully selecting stock, removing predators, feeding and fertilizing, such brackish water farm, already yield more than three times as much flesh per hectare as the land.

Transplantation is one shortcut to more regular sea farming. Young plaice were taken from their normal overcrowded feeding grounds along the Danish and Dutch coasts to the Dogger Bank, where more good feed is available. Their growth speeded up considerably.

Soviet transfer of Baltic Sea herring to the Sea of Azov doubled their growth rate. Pacific salmon has taken on in the North Atlantic and is obviously moving south. Transplantation of food fish and maintaining the regular stock play an important role in several countries, e.g., Pakistan, Iraq (see Ahmad, 1956) and U.S.S.R. (Ovchynnyk, 1961).

B. CULTIVATION

1. *Fish Farming*

In a number of countries, pisciculture, sometimes since ancient times, has been important. Owing to industrial and urban pollution and squandering of water in hydroelectric and irrigation projects, artificial cultivation is becoming more prevalent. The yields obtained depend on geographical location, temperature, degree of fertilizing, etc., and may vary from 40 to 4,000 kg. hectare; the latter figure is from Southern China and the former from unfertilized waters in temperate regions (Anonymous, 1961d).

Reports of studies in the United States and Canada on fish pond production clearly demonstrate that fish ponds yield more meat (animal protein) per hectare than cattle. One experimental farm in Illinois obtained 225 kg. of fish meat per hectare, while 85–150 kg. of beef was produced. When heavily fertilized, 600 kg. of fish have been raised.

Various *Tilapia* species are cultivated in many tropical countries (Chimits, 1957; Anonymous, 1960a). These fish live on algae and need no extra feed, yet may give yields of 400 kg./hectare.

The cultivation of fish in Eastern and Western Europe is discussed in Volume I, Chapters 2 and 3; for fish cultivation in the Soviet Union reference is made to Ovchynnyk (1961) and Borgstrom (1961b). A more recent Soviet development is making an effort to provide each farm village with fish ponds. Major cities are also constructing large fish-raising establishments. It is also contemplated in this way to find means of utilizing sewage and city wastes more efficiently by converting them into food.

In Germany and Czechoslovakia almost every large town has its fish farm. Carp and eel are the chief cultivated fish.

A special Soviet feature is the joint raising of fish and ducks, thereby increasing production of each (Pachulkij, 1957). The droppings of these birds raise appreciably the productivity level of the ponds. White Russia calculates to obtain annually from its 20,000–25,000 hectares of cultivated fish ponds 10,000 metric tons of fish and 8,000 tons of duck meat (Lyachnovich, 1961).

There are big areas of marshy land, particularly in Africa and in the West Indies, that could be developed for fish farming. Fish ponds could also be introduced wherever there is well-watered undeveloped land available, or even in developed land as part of mixed farming (together or alternating with rice and regular agricultural crops). Moreover, along the coasts there are many areas where marine fish ponds could be organized.

2. *Oyster Cultivation*

The artificial cultivation of blue mussels has expanded appreciably during the postwar period in most of the West European countries (see tabulation below) bordering the North Sea and the Atlantic (Meyer-Waarden, 1960). The mussels grow to market size in two years. In suitable shallow waters, rich in nutrients and plankton production, 12.5–25 metric tons per hectare can be produced. Those waters are gradually fed with new loads of fertilizing nutrients brought out by major rivers, such as the Elbe (no less than 4 metric tons of P_2O_5 per day) and the Thames (6 metric tons).

OYSTER PRODUCTION IN WESTERN EUROPE

Netherlands	63,429	Spain	4,479
France	24,000	United Kingdom	2,740
Denmark	17,386	Eire	2,255
Western Germany	6,026	Belgium	576

Prior to marketing, the mussels are taken to cleansing tanks to rinse away sand and empty the gut. Most oysters in Australia are produced artificially in large enterprises—in 1957, 4,500 metric tons (Sardone, 1959).

3. *New Fishes*

Numerous papers are available on the adaptation of *Tilapia* to other regions than the native African habitat and the growing output of fish through cultivation of these species.

Since the Middle Ages eels have attracted attention as a fish that grows readily under artificial conditions and may become increasingly important in future sewage utilization. Albufera, the rice region in the vicinity of Valencia, raises eels successfully. Eel farms are reported from Denmark, Japan, Kenya (Frost, 1954), etc.

A significant feature in the future development of fish cultivation is the breeding of new species, crossings or strains exhibiting better feed utilization and more rapid growth or greater disease resistance. Soviet science appears to have led in this development (Ovchynnyk, 1961). Interesting accomplishments in this respect are also reported from China (Saburenko, 1961).

4. *Man-made Reservoirs*

Not only technical development threatened in various ways the existence and productive capacity of natural waters, but large new water masses have been created. Thus it is maintained that in the United States there are more than 5 million hectares (12 million acres) of man-made reservoirs, which could provide habitats for fish. So far, these water resources have been poorly utilized. There are a few exceptions (Beckman and Kutkuhn, 1953).

The Soviet Union reports that no less than 5 million hectares (12.5 million acres) of artificial water have been created through their many hydroelectric dams and irrigation reservoirs, largely in recent years. Efforts, although painstaking, are made mostly to transform these into productive waters for food fish. Many biological problems still remain unsolved for such schemes, but intense research is being pursued both to use the photic zones and to get the entire water volume producing. It is calculated that the yearly fish catch potential of these dams exceeds half a million metric tons.

Many new large bodies of water have also come into existence through Chinese industrialization, estimated at 1.58 million hectares and rendering 24 kg./hectare (Saburenkov, 1961). Thirty such reservoirs—the size of 600 to 14,000 hectares—are completed, and 80 additional ones (100–230,000 hectares) are in process of construction (Denisov, 1961).

In India, the large Mettur reservoir in the state of Madras is being developed for fish cultivation and in combination with a dehydration plant.

5. *Sewage Utilization*

The sewage works of Munich pioneered in the 1930's the utilization of this resource by attaching fish farms where the effluent was converted, via algae, mollusks, and insects, into carp and tench—produced at a rate of 500 kg./hectare. One hectare of water purifies the mechanically classified sewage from 2,000 persons, yielding 27.5 kg. of protein. Raw sewage is extensively converted into food via fish in the Far East (Java, India, e.g., Calcutta). For a review of this field, see Mortimer (1954) and Hickling (1961). The effluent from large treatment tanks induces fish yields as high as 4 metric tons per hectare per year. Several fish species, not only carp, are grown.

It should be added as a note that, in many densely populated regions of the United States and Western Europe, sewage finds its way into natural waters, affecting productivity and fish yields. The extensive use of fertilizers has also increased the amount of nitrogen and phosphorus draining into lakes and streams, e.g., in Wisconsin.

C. SEAWEED AND PLANKTON AS FOOD

1. *Seaweed*

Seaweed resources have been grossly overrated as a future source of food. Most estimates have been based on the uniquely productive submerged expanses of attached seaweed off the coasts of Norway and the British Isles (Newton, 1951). More correct and realistic figures reveal the slow growth and poor productivity in many coastal regions, e.g., the German North Sea and Baltic coasts (Schwenke, 1960). Neither brown nor red algae occur in reliable, sufficiently large populations; most is used up as animal foodstuff (Black and Woodward, 1957).

Their value as direct human food is also exaggerated. The human gastric system is not able to digest the well-protected structures of the algae cells, as is the case with terrestrial plants. Even when favorable results are reported for individual constituents, such as carbohydrates, fats, and proteins, availability remains decisive. Surface bacteria providing vital B_{12} belong in another category, as do minerals too. Drying and making them into finely ground powder naturally facilitates accessibility.

Since antiquity, seaweed has been utilized in agriculture as fodder and a valuable manure. In this way it still plays a role in human feeding. In China it is used in growing potatoes, peanuts and other crops (Newton, 1951), and on the Hebrides and Aran Islands for raising potato crops. In the coastal areas of Alaska and Scandinavia, seaweed still is gathered as a valuable manure. In Ceylon and India, seaweed is similarly used for fertilizing coconut trees and several other crops. Iodine is in this way conveyed to the crops, as Soviet studies prove.

Seaweed was presumably first used directly as human food by the Chinese. They still consume appreciable quantities. Its chief importance, however, is as bulk filling material—alginates and related compounds. The coasts of the Japanese islands are well suited for large-scale growth and harvesting of seaweeds (Anonymous, 1957). One-tenth of their daily food consists of algae—see Chapter 6 of this volume. Great efforts are being made in Japan to expand seaweed production for food purposes. In Hawaii, a number of species are eaten, and there is a considerable trade in them in Honolulu, some even being imported from China and Japan.

The *brown seaweeds* are used very extensively for food in Japan. The smaller species are dried, but the larger kinds ar used as cover for noodles, toasted or served with rice or soup. Two *Laminaria* species are also used for sweetening and seasoning, owing to their high mannite and glutamic acid content. A substitute for soybean sauce has been made from brown algae.

The *red seaweeds* are also used for human consumption among both Eastern and Western peoples. In the West, however, they are harvested only to a very small extent.

The Japanese "hori" is made chiefly from the red seaweed *Porphyra* sp., cultivated on bamboo branches. Hori is toasted and eaten hot as a delicacy. It is used in dried form to wrap rice balls or as a flavoring. Another *Porphyra* is used for the making of laver. It has been used fried, boiled, fermented, or made into a bread. Earlier, this food was prepared also in South Wales (Newton, 1951).

2. *Plankton Utilization*

a. HARVESTING

Can man tap the plankton granaries of the ocean? There is no known way to catch sufficient amounts of plankton for any reasonable economic return for the effort spent. Furthermore, a substantial part of the production of the nannoplankton—in some waters nine-tenths—will not be harvested. No device can change the basic fact that approximately 7500 $m.^3$ of ocean water is required to obtain one day's ration for man—calculated in calories. Even in very productive waters, this implies 2.5 hours of effective filtering. It is, consequently, not possible to feed even the crew on such plankton harvesters, far less provide the fuel required for such a futile operation.

In the heavily fished waters of the North Sea, the standing crop of zooplankton is estimated at more than 10 million tons net weight. But in a good year North Sea fishermen average some 58 tons of herring per 100 hours. But they would have to strain approximately 58 million tons of North Sea water to gather an equivalent amount of plankton.

Jackson (1954) calculated the cost of various harvesting methods and returns. He concluded that such filtered plankton would require a price twenty times what is charged for the highest priced fish. Taking these factors into consideration, the mussel, shrimp, fish, and whale emerge in a new perspective. They constitute, in effect, multimillion armies of unpaid workers doing all the filtering, concentrating, and refining of the planktonic food, thus serving man end products that are not only delicious but also have superior value, are more readily accessible to our gastric system, and are in an infinitely more convenient form.

b. Plankton Cultivation

Large-scale cultivation of the fresh-water alga *Chlorella* has succeeded, but at excessive cost (Burlew, 1953). Experiments are proceeding in the United Kingdom to grow the marine diatom *Phaeodactylum* on a large scale (Raymont and Adams, 1958). Any closed system requires injections of carbon dioxide, cooking, stirring (for optimal light), and continuous harvesting. Mineral nutrients have to be added successively. Large extra costs thus become involved—see reviews by Pearsall (1951) and Borgstrom (1952). Open vessels run the risk of contamination with interfering organisms. Both these organisms have competition in the sea. As to future cropping in the sea, these contaminants represent the weeds.

Owing to these complications, direct cultivation in the oceans has been contemplated. Shallow sea areas may be fenced off with plastics. Long transparent tubing or sheets may be brought to float on the sea surface, making stirring superfluous.

High protein yields are feasible. Algal protein quality is not inferior, even if it does not match that of most other plants. But, as indicated above, most plant cells are not directly accessible to human gastric juices, encased as they are in cellulose of silicon-enforced walls. The cultivation of various planktonic algae appears, for a long time ahead, rather to offer potentialities as feeding material to ruminants or as a food source for yeasts or shellfish, if the costs involved can be met.

D. Hazards

In most discussions on the use of fish in human feeding, little attention has been given to the obvious hazards that do exist. Many conditions are seriously jeopardizing the future use of fish as food or limiting its value or economic utilization (Clarke and Bishop, 1948; Rose, 1957; Geiger, 1958) (see also Chapter 18 on radioactive dangers).

1. *Poisonous Fishes*

In many populous regions of the world, and particularly in its warmer sections, fish poisonings are not infrequent. This was dramatically realized during World War II in the Pacific area. As much as one-fifth of the reef fishes were found to be toxic (Hessel *et al.*, 1960). Many sections of the Caribbean are harassed by poisonous fishes (Randall, 1961). The whole field of poisonous fishes has been reviewed in Chapter 15, this volume. Only a few general comments will be made here. A distinction can be drawn between those fish having a flesh which is consistently toxic to humans and those having special glands or organs with poisons, e.g., shark, eels, and puffers, and finally, those fishes carrying ciguatera toxin (Banner *et al.*, 1961). There are, however, some pronounced changes in the regional patterns of ciguatera poisonings over the years, discovered by Copenhagen (1958). Several scombroid fishes form histamine, via specific surface bacteria (see Volume I, Chapter 10).

Clupeoid fishes, particularly *Sardinella*, show a seasonal toxicity presumably due to the ingestion of particular plankton organisms. Reports on such poisonings are rather common from the tropical Pacific and Indian Ocean, e.g., the Marshalls, New Caledonia, Fiji, Indonesia, and Ceylon. Similar poisonings are seasonally reported from fresh-water fish in Northern Germany and Russia—see Chapter 11 of this volume.

Randall (1958) suggested the possibility also that ciguatera might be induced by a toxic compound in the feed of incriminated fishes. In all waters toxic dinoflagellates of the species *Gymnodinium* are a potential hazard whenever conditions for a bloom develop. Several species of this particular genus are behind a number of shellfish poisonings (Chapter 11, this volume).

2. *Snakes*

Sea snakes, several of which are poisonous, abound in the tropical Pacific. Each time the Galathea expedition entered shallow waters, snakes were regularly in the catch—once, in a single haul, 40 belonging to six different species. The Gulf of Siam is particularly noted for its profusion of snakes. It is strange that the Atlantic still appears to be free of snakes (Volsøe, 1956).

3. *Human Diseases*

Fish are definitely incriminated as a major agent of erysipeloid, entering through scratches and wounds. This disease has become almost an occupational disorder among fishermen and those working in fish-handling and filleting establishments. Skate seem to be particularly dangerous in this respect, but most fish seem to carry the involved bacteria. Traumatic injuries and a moist environment are conducive to the development of this trouble. This bacteria—*Erysipelothrix*—appears to be a common contaminant in the slime of most fishes, even when healthy (Sneath *et al.*, 1951; Price and Bennett, 1951).

Tapeworms are spread to human beings via fish in the entire circumpolar region and constitute a serious hazard to the population of

Alaska, the Soviet Union, and Scandinavia—see further Chapters 16 and 17 of this volume.

Botulism E in particular is fish-borne and is reported from several countries (see Chapter 11 of this volume). Some fish, especially mullets, occasionally appear to induce hallucinations (Helfrich and Banner, 1960).

4. *Infestation*

Several insects lay their eggs in the dried fish of warmer regions. Dermistids are particularly incriminated. This is a scourge of tropical Africa, where up to 50% of the fish weight may be attributed to such larvae.

5. *Fish Infections*

A number of bacterial infections of fish are discussed in Chapters 15 and 16 of this volume. Red virus constitutes a serious and, it appears, growing threat to carp raising in continental Europe and the Soviet Union. Particularly alarming are the inroads protozoans appear to be making into the fish kingdom. Jellied fish, due to such attacks, are reported from a great number of countries; see further Chapter 15 of this volume.

A number of diseases have harassed United States oyster cultivation. Besides the traditional pest of starfish, strange new maladies have appeared on the scene.

6. *Mass Mortality*

Mass mortality of fish is regularly reported from certain regions of the globe, but predominantly in warmer waters: the Red Sea, the western part of the Indian Ocean, off South West Africa, etc. Almost every year during December and January such a dying off of fish takes place in the Walvis region of South West Africa. A certain interplay between meteorological and oceanographical conditions appears to induce this mortality. There is a permanent area of approximately 6,000 square miles where the sea bottom is characterized by a sulfide diatomaceous ooze. Occasionally the Benguela Current is pushed back by considerable masses of highly saline subtropical Atlantic Ocean water. This results in increases of 5–6°C. in surface water temperature, in turn causing destruction of the coastal plankton. The dissolved oxygen becomes depleted, and in this anaerobic environment sulfate-reducing microorganisms flourish and the production of hydrogen sulfide ensues. Particularly after northerly winds this hydrogen sulfide reaches the surface and kills off the fish (Copenhagen, 1958). Sudden upward or downward temperature changes may also induce killing.

Under certain conditions, there may occur a "bloom," or mass production of dinoflagellates, belonging to the genus *Gymnodinium*, or other types of toxic plankton (e.g., the peridinian *Gonyaulax* sp. reported from Japan, United States, the Pacific, the Caribbean, and Western Europe); fish may be destroyed indirectly in this way (see Chapter 19, this volume). In fresh waters the algae *Microcystis aeruginosa* is known to be toxic to fish and to induce water blooms. Killing may sometimes be accompanied by a mass retreat of fish, as is the case with *Noctiluca* blooms off South Africa and off the west coast of India (Bhimachar and George, 1950). In most cases these blooms finally result in large scale fouling and oxygen depletion. This also applies to the famous Red Sea bloom caused by the blue-green algae *Trichodesmium erythreum*.

7. *Pollution and Dams*

The future of the salmon is a cause of much worry. Because of deforestation in the New England states, followed by heavy soil erosion and industrial pollution, the rich salmon stock in this region now is a thing of the past. The building of high dams such as Grand Coulee prevents salmon from reaching their spawning grounds in inland streams. Discharge of waste from pulp and paper mills further renders the water unfit for fish life. Depletion is the final result.

Gradually the hydroelectric establishments in the rivers of North Sweden are creating a serious threat to the flourishing salmon fishing industry of the Baltic. A definite decline has already been observed. The particular arrangements to guarantee access to the spawning ground and to ensure satisfactory escape apparently are inadequate. This is a crucial problem to the future of salmon fishing all over the world.

Many biologists consider the great fisheries of the Pacific Coast doomed to extinction. Efforts to change the habits of migratory fish have been extremely costly. The moving of salmon in tank trucks past the Grand Coulee has so far cost 5 million dollars. Eight years afterward the decline in the salmon stock still is apparent. The commercial catch of this region is now reduced to approximately half its 30-year average.

Each year industrialized or industrializing countries report major fish loss owing to pollution of natural waters chiefly by foreign chemicals or by overloading with oxygen-depleting organic compounds.

8. *Ghost Nets*

A novel problem in many parts of the world is created by lost nets. This hazard to fishing is especially significant around Iceland where many kilometers of net are lost each year. Because of the new synthetic materials employed in net making, nets no longer rot and disappear but remain intact indefinitely (Kristjansson, 1960).

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CHAPTER 8

The Role of Marine and Fresh-Water Foods in the Japanese Diet

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I. Diet

A survey is conducted four times a year on the intake of foods. Physical measurements, such as height, weight, and other physical body characteristics—likely to reflect the nutritional standard and to reveal deficiencies—are registered. On the basis of the dietary figures, intake of various nutrients is calculated.

A. Food Intake

The consumptional pattern has changed substantially in latter years. Grains and potatoes show a steady decline, while the consumption of fish, meats, poultry, and eggs has increased. At the same time, the intake of fats, oils, and sugar has expanded in a conspicuous manner (Table I). The differences between the urban and rural populations are not too great. They show up most in the critical area of consumption of fish and other animal products, which is 30% below the average for the urban population. In rural districts, less sugar is consumed and more potatoes.

TABLE I

Intake of Foods as to Commodities per Capita per Day (in Grams)[a]

Foods	Annual average per period		
	1949-1951	1952-1954	1955-1957
Cereals and nuts	483.0	478.6	471.2
Potatoes	136.9	78.5	75.6
Sugars	7.9	14.9	13.9
Fats and oils	2.5	4.2	4.8
Beans and other legumes	55.5	68.7	70.0
Fish, meat, egg, and dairy products	81.9	112.4	112.0
Vegetables and fruits	227.6	209.1	233.2
Seaweeds	3.4	4.4	4.8
Processed vegetables	46.7	49.4	56.9
Miscellaneous	33.5	41.9	58.1
	1078.9	1062.1	1100.5

[a] Source: Ministry of Health and Welfare, Japanese Government.

B. Intake of Nutrients

The nutrient intake is calculated from the dietary figures for consumption and on the basis of standard tables for food composition (Table IIA). These results disclose that the nutritional status has improved since the

TABLE IIA

Intake of Calories and Nutrients per Capita per Day (Whole Country)

Calories and Nutrients	1949-1951	1952-1954	1955-1957
Calories	2107	2083	2095
Protein (g.)			
Total	67	69.1	69.4
Animal	16	22.3	22.7
Vegetable	50.3	46.9	46.8
Carbohydrate (g.)	422	406	406.5
Fat (g.)	17	204	21.1[a]
Minerals			
Calcium (g.)	0.25	0.37	0.37
Phosphorus (g.)	1.81	1.82	1.36
Iron (mg.)	47	62	15[b]
Vitamins			
A (I.U.)	2379	2745	1667
B_1 (mg.)	1.57	1.11	1.14
B_2 (mg.)	0.73	0.66	0.69
C (mg.)	107	75	77

[a] Average for 1955-1956.

[b] Change in basis for calculation.

war ended. This change is particularly noticeable in the rural areas (Table IIB and C).

TABLE IIB

Intake of Calories and Nutrients per Capita per Day (Rural Areas)

Calories and nutrients	1946	1956	Difference 1946-1956	% Change
Calories	2084	2152	68	+ 3.3
Protein (g.)				
Total	59.8	68.3	9.5	+ 16.2
Animal	5.9	19.8	13.9	+235.6
Vegetable	52.9	48.5	— 4.4	— 8.3
Carbohydrate (g.)	—	427	—	—
Fat (g.)	12.7	19.2	6.5	+ 51.2
Minerals				
Calcium (g.)	0.253	0.377	0.124	+ 49.0
Phosphorus (g.)	2.05	1.41	— 0.64	— 31.2
Iron (mg.)	47	17	—30[a]	63.8
Vitamins				
A (I.U.)	4427	1582	—2845[a]	— 64.3
B_1 (mg.)	1.98	1.07	— 0.91	— 45.9
B_2 (mg.)	0.71	0.69	— 0.02	— 2.8
C (mg.)	186	78	— 108	— 58.1

[a] Change in basis for calculation.

TABLE IIC

Intake of Calories and Nutrients per Capita per Day (Urban Areas)

Calories and nutrients	1946	1956	Difference 1946–1956	% Change
Calories	1721	2034	313	+ 18.2
Protein (g.)				
Total	59.5	69.8	10.3	+ 17.3
Animal	15.2	25.4	10.2	+ 67.1
Vegetable	44.3	44.5	0.2	+ 0.5
Carbohydrate (g.)	—	384	—	—
Fat (g.)	16.6	24.3	7.7	+ 46.3
Minerals				
Calcium (g.)	0.253	0.381	0.128	+ 50.6
Phosphorus (g.)	1.87	1.30	— 0.57	— 30.5
Iron (mg.)	48	15	—33[a]	— 68.8
Vitamins				
A (I.U.)	4854	1789	—3065[a]	— 63.1
B_1 (mg.)	1.63	1.18	— 0.45	— 27.6
B_2 (mg.)	0.64	0.72	0.08	— 12.5
C (mg.)	188	75	— 113	— 60.1

[a] Change in basis for calculation.

C. NUTRITIONAL DEFICIENCIES

In spite of improvements in the over-all nutritional condition, many deficiencies still exist. This can be inferred from the discrepancies between the actual intake of nutrients and the standard requirements. The intake is below standard in calories, as well as in all major nutrients such as good high-quality protein, fats, vitamins, and calcium. Furthermore, the figures for intake are calculated without giving due consideration to the losses taking place during cooking. The urban population enjoys a 26% higher intake of animal protein and fat but 10% less plant protein and calories than in the rural sector. The intake of calories, protein, and fat increases every year, while that of vitamins and calcium has remained almost unchanged during recent years.

D. PHYSICAL SYMPTOMS

Anemia, xerophthalmia, and cheilosis generally result from dietary shortcomings. These figures are not high. For anemia they amount to 2.5% of the population and for eye disturbances due to lack of vitamin A, 3%; cheilosis is encountered in 5% of the population. Approximately one-fourth of the nation shows one or another symptom attributable to lack of some essential nutrient.

E. NEEDS FOR IMPROVED DIET

High-quality protein is still needed in great quantity. Besides meats, eggs, milk, and soybeans, the consumption of fish should be effectively increased to provide additional amounts. Fish, together with soybeans, are considered the most promising sources from which to meet the needs of the expanding population. A greater intake of vitamin-rich food is desirable. Although milk and butter are effectively promoted, the measures of fortification mean more. This is done in rice, flour, "miso," and oleomargarine. Calcium is scarce, and some foods are now enriched with calcium.

II. Catch and Consumption

A. CATCH

Japan, an island country, is geographically favored with marine products. Next to China, it is the leading fishing nation of the world (see Chapter 7, this volume). Approximately 60% of the total catch was utilized as food, while the remainder was used as fertilizers and animal feed. Nowadays, however, some 90% goes for human consumption (Table III). Table I shows postwar supply and consumption of various foods and marine products.

TABLE III

SUMMARY OF CATCHES BY FISHERIES AND AQUICULTURE[a]

Fish	1953	1954	1955	1956
Fish, total	877,538	876,288	959,652	933,580
Shellfish	84,887	83,535	89,003	103,567
Anchovy	64,927	81,075	104,406	92,455
Saury	67,643	78,058	132,534	87,417
Mackerel	62,607	79,305	65,174	70,986
Pampano	63,978	67,070	63,577	65,774
Alaska pollock	60,069	64,432	61,647	62,639
Sardine	91,633	65,504	56,358	55,014
Salmon	12,088	21,290	47,802	41,268
Flounder, halibut, sole	34,211	34,463	33,189	40,040
Other marine animals, total	162,977	167,483	172,097	148,190
Common squid	112,023	106,335	102,245	79,863
Other squids	12,757	11,903	13,614	14,664
Devilfish	11,184	11,686	12,701	12,544

[a] Unit: 1000 kan = 3.75 tons.

The total catch at present surpasses the prewar level. Numerous kinds of fish and shellfish are landed and eaten in Japan. The number is well over a hundred, counting only major kinds (Table IV). Furthermore, there is quite a diversity of processed products such as canned, frozen, dried, cured, smoked, and pickled types.

TABLE IV

CATCHES OF SELECTED SPECIES IN THE PREWAR AND POSTWAR PERIODS[a]

	1935–1937		1952–1956		
Fish	Average (A) in 1000 kan[b]	%	Average (B) in 1000 kan[b]	%	B/A × 100
Total amount	1,165,669	100	1,327,584	100	—
Sardine	319,885	27.4	168,364	12.6	52.6
Saury	26,849	2.3	85,183	6.4	317.2
Mackerel	31,574	2.0	70,905	5.3	224.5
Cod	48,963	4.1	69,725	5.3	142.5
Pampano	7,820	0.6	63,078	4.7	806.6
Tuna	17,925	1.5	54,314	4.1	303.0
Herring	70,829	6.0	43,236	3.2	61.0
Flounder	19,261	1.6	35,013	2.6	181.7
Skipjack	23,576	2.0	30,224	2.2	128.5
Salmon	52,166	4.4	26,604	2.0	50.9
Cuttlefish	20,210	1.7	131,276	9.9	649.5

[a] Source: Ministry of Agriculture and Forestry, Japanese Government.

[b] Unit: 1000 kan = 3.75 tons.

Whale meat, together with fish and shellfish, plays an important role in Japanese nutrition as a protein and fat source, and its production has increased greatly in recent years (Table V).

TABLE V

WHALE CATCHES[a]

	1954	1955	1956
Pelagic whaling, Antarctic Ocean			
Number of whales caught	—	5956	6462
Production (metric tons):			
whale oil	—	62,377	69,505
meat (including skin) for food	—	39,676	44,642
Pelagic whaling, North Pacific Ocean			
Number of whales caught	2216	2652	3186
Production (metric tons):			
whale oil	17,547	19,026	24,922
meat (including skin) for food	15,922	12,223	15,915
Coastal whaling			
Number of whales caught	2354	2387	3284
Amounts of production (metric tons):			
whale oil	5638	5853	7859
meat (including skin) for food	15,169	16,095	18,522
Small-type whaling			
Number of whales caught	803	871	1210
Amounts of production (metric tons):			
whale oil	2671	2919	3553
meat (including skin) for food	1779	2006	2482

[a] Source: Ministry of Agriculture and Forestry, Japan.

Seaweeds are also essential as mineral and vitamin sources, and many kinds of such algae are being gathered, and are also cultivated. Several seaweeds are potent sources of vitamin B_{12}. This is particularly true of one of the most common species, the red algae *Porphyra tenera*, which is the basis for the popular dish "asakusanori."

B. CONSUMPTION

Several difficulties prevail in procuring reliable statistics picturing the true scope of the fisheries. A considerable amount of fish being caught does not enter into the statistics. This means that the actual consumption of seafood presumably largely exceeds the catch as given in official statistics.

Figures for consumption of seafood in Japan vary considerably. This most likely is due to the fact that the amount of edible flesh is not always computed. The great diversification of products may partly explain these discrepancies.

Fish constitutes almost 5% of the total caloric intake, a larger proportion of the total protein intake (25%), and still more in relation to the animal protein being consumed.

C. Animal Protein

The per capita consumption of fish and shellfish meat in Japan almost equals that in Scandinavia, but the relative role of fish is much greater owing to the low level of total intake of animal protein. This latter figure is, however, at present on the increase.

Fish and shellfish protein constitute a major portion of this high-quality protein, amounting to 69% as a national average, but less in urban regions (64%) and more in rural areas (78%) (see Table VI).

D. Increased Production

Emphasis is now put on enhancing the production through agriculture of animal protein (milk, meat, and eggs). This progress will be slow and is impeded by the simultaneous growth of the population in numbers. On the other hand, research and development are encouraged in the field of foods, such as *Chlorella* and food yeast. Most practical so far, however, are expanded catching of fish and the growing of the protein-rich soybean. Both are traditional in Japan, and the population has developed great skill in their preparation as food. Thus, manufacture of fish sausage is in latter years spreading extensively in the rural areas, this being a cheap food item.

With improved storage facilities and a more efficient utilization of fish and shellfish, it appears possible to attain higher figures for intake of nutrients than hitherto even without an enlargement of the total catch.

III. Nutritive Value of Japanese Seafood

Japanese species do not differ as to composition from what is reported from other fishing nations of the world. A few analytical data referring to more recent data and to species either specific to or dominating in Japanese landings are listed in Table VII.

A. Protein

The nutritive aspects of fish and shellfish protein are discussed in Chapter 2 of this volume. Some pertinent data on important Japanese fish species are listed in Table VII.

B. Fat

Both body fat, deposited in the muscle tissues, as in sardines, herring, salmon, and tuna, and liver fat, as in shark and cod, are important sources of food. The amount of both these types of fats varies depending

TABLE VI
The Animal and Fish Protein Balance

Protein	1952	1953	1954	1955	1956	1957	1958	1959
Total population								
Animal (% of total protein intake)	32.2	32.1	32.2	31.7	32.7	33.3	32.5	33.9
Fish and shellfish (% of animal protein)	81.9	82.2	80.1	80.0	74.3	75.8	71.8	69.4
Urban population								
Animal (% of total protein intake)	35.1	35.7	35.3	36.1	36.4	36.5	37.7	38.0
Fish and shellfish (% of animal protein)	77.3	77.8	75.8	73.7	68.8	72.8	77.1	64.3
Rural population								
Animal (% of total protein intake)	30.2	29.9	29.4	28.2	29.0	28.5	28.2	28.3
Fish and shellfish (% of animal protein)	86.8	86.0	86.5	86.9	82.3	82.0	79.1	77.9

on species, age, and living conditions of the fish, and those variations are more marked in fat than in any other ingredient. The composition of fat is discussed in Volume I, Chapters 7 and 8. As to the possible injurious effect of such highly unsaturated fatty acids due to the formation of toxic substances through oxidation, reference is made to Chapter 3 in this volume.

C. MINERALS

A number of minerals contained in fish and shellfish are essential to the diet. Several of these occur in trace quantities, but are nevertheless essential, e.g., bromine, boron, manganese, lithium, selenium, arsenic, and cobalt. In addition there is a group the importance of which to human nutrition has not so far been clarified, such as silicon, caesium, silver, mercury, gadolinium, tin, chromium, nickel, and aluminum. Iodine and calcium are quite essential and occur more abundantly in fish and shellfish than in meat and poultry. The amount of these minerals varies depending on the kind of fish, living conditions, and organ. The iodine content is highest in shellfish, followed by fish. In one investigated class it was most abundant in viscera, followed by the meat, and lowest in the skin. The calcium content of pond smelt living in sea water is higher than when this same fish develops in a fresh-water lake.

D. VITAMINS

At present, there is a shortage of vitamin A in the Japanese diet, and no less than 95% of what is consumed comes from plant sources. More efficient use should be made of the rich marine sources in this respect. In the postwar period, an industry has been developed using fish liver oil as a raw material. Concentrated vitamin A oil thus obtained is used for enriching oleomargarine, "miso" (a soybean product), and fish sausages.

A great number of vitamin analyses are available from Japan. Several of these are referred to and partially listed in Chapters 6 and 13 of Volume I. Mention should be made of the studies by Yanase on B_6, round herring being a particularly rich source; B_{12} was investigated by Hashimoto, as well as by Yanase. The liver of the mullet and the saury contains many times more B_{12} than any other source. Rather large amounts are also found in the liver of pampano and sea bream. It was mentioned by Higashi (Volume I, Chapter 13) that the lamprey by tradition is well known to be a good all-round source of most vitamins, particularly of those belonging to the fat-soluble group. Some selected but typical figures have been compiled in a special Table VII. It has already been stated that several seaweeds constitute potent sources of B_{12}.

TABLE VII

COMPOSITION (PER 100 G.) OF MAJOR JAPANESE SEAFOOD

Seafood	Calorie (cal.)	Moisture (g.)	Protein (g.)	Fat (g.)	Carbohydrate (g.)	Ash (g.)
Alaska pollock	72	81.0	16.6	0.6	0.1	1.7
Atka mackerel	110	77.0	17.0	4.6	0.2	1.2
Bastard halibut	100	75.7	22.0	1.0	0.7	0.6
Bluefin tuna	107	73.2	24.0	1.0	0.6	1.2
	311	52.6	21.0	25.0	0.5	0.9
Conger eel	150	71.5	19.0	8.0	0.5	1.0
Croaker	144	70.0	22.0	6.0	0.6	1.4
Dogfish	314	50.0	25.0	23.5	0.5	1.0
Flounder	109	74.0	22.0	2.0	0.8	1.2
Herring	144	73.5	16.0	8.5	0.8	1.2
Mackerel	111	76.0	18.0	4.0	0.7	1.3
Pampano	110	75.0	20.0	3.0	0.7	1.3
Salmon	156	70.5	19.0	8.7	0.3	1.5
Sardine	125	75.0	17.0	6.0	0.8	1.2
Saury	207	64.5	20.0	14.0	0.2	1.3
Skipjack	130	70.0	25.0	3.0	0.7	1.3
Sweet smelt	95	78.5	17.0	3.0	0.1	1.4
Yellowtail	194	63.0	25.0	10.0	1.0	1.0
King crab	91	76.0	20.0	0.5	1.5	2.0
Spiny lobster	80	80.0	16.0	1.1	1.5	1.4
"Shibaebi" shrimp	55	86.0	11.5	0.7	0.7	1.1
Abalone	100	73.4	23.5	0.4	0.7	2.0
Common scallop	100	74.2	20.8	0.8	2.4	1.8
Fresh-water clam	99	76.0	15.0	1.8	5.6	1.6
Hard clam	61	84.8	10.0	1.2	2.5	1.5
Oyster	93	79.6	10.0	3.6	5.1	1.7
Short-necked clam	60	85.4	10.0	1.3	2.1	1.2
Squid	79	80.3	17.0	1.0	0.5	1.2
Cherry salmon	136	71.0	22.0	5.2	0.4	1.4
Common carp	172	67.0	22.0	9.0	0.7	1.3
Crucian carp	98	78.0	17.0	3.0	0.7	1.3
Eel	243	60.7	20.0	18.0	0.3	1.0
Pond smelt	95	76.8	17.1	2.9	0.2	3.0
Cod roe	112	71.5	21.0	3.0	0.2	4.3
Herring roe	139	69.0	25.6	4.1	0	1.3
Salmon roe	238	53.0	25.0	15.0	0.8	6.2
Whale meat	120	72.7	23.3	3.0	0	1.0

TABLE VII (*Continued*)

Calcium (mg.)	Phosphorus (mg.)	Iron (mg.)	Vit. A (I.U.)	Vit. B_1 (mg.)	Vit. B_2 (mg.)	Niacin (mg.)	Vit. C (mg.)
9	160	0.4	60	0.15	0.1	2.0	0
—	—	—	80	0.09	0.04	—	0
23	180	0.5	120	0.10	0.20	1.7	2
—	—	—	20	0.10	0.09	—	—
11	350	9	100	0.10	0.08	5.0	2
350	120	4	800	0.06	0.04	—	0
40	280	2	30	0.10	0.07	—	0
—	500	—	1200	—	—	—	0
31	150	0.6	100	0.1	0.1	3.5	3
34	250	1.8	100	0.01	0.2	5	0
5	190	1.8	50	0.15	0.2	8.0	3
12	200	1.7	40	0.15	0.08	6.5	2
32	150	4	110	0.25	0.2	7.0	0
50	240	2	60	0.02	0.15	10.0	2
22	190	3	120	0.05	0.10	6.0	2
6	220	1.7	40	0.03	0.15	10.0	2
53	190	2	120	0.04	0.10	—	0
6	220	0.7	100	0.14	0.10	7.2	2
59	—	4	—	0.01	—	—	—
70	78	1	10	0.01	0.1	1.9	3
25	400	4	20	0.10	0.11	2.2	2
32	190	3	15	0.20	0.06	1.5	2
—	—	—	8	0.04	0.1	1.4	3
180	141	21	130	0.04	0.15	—	10
60	94	13	100	0.05	0.15	1.5	5
40	140	8	100	0.3	0.2	1.2	5
—	78	7	100	0.04	0.15	1.5	10
12	290	0.4	5	0.03	0.12	3.0	0
13	990	1.1	100	0.22	0.07	3.5	0
72	180	2	20	0.4	0.08	2.0	0
150	150	2	50	0.38	0.10	2.4	0
150	180	1	3000	0.01	0.1	3.0	1.5
750	680	5	100	0.13	0.36	1.9	0
22	190	1.3	300	1.00	0.21	0.9	14
39	61	1	50	0.15	0.22	—	0
99	1200	6	500	0.61	0.08	—	14
11	190	5	120	0.10	0.08	—	0

Skin, frequently eaten together with the flesh, is a good source of vitamin A.

IV. Seafood in the Diet

As stated above, many kinds of fish and shellfish are captured in large quantities, and there are quite a number of methods of cooking and processing. The following basic methods are those most commonly used in cooking and in the major processed products.

A. Cooking Methods

1. *Sashimi*

This dish consists of raw fish. Head, bones, skin, and viscera are removed. The meat is sliced into appropriate pieces and eaten with soy sauce, mixed with spices or vinegar. The meat is served together with vegetables. Certain kinds of shellfish are also eaten in this manner.

2. *Shioyaki*

Viscera, and/or head and bones are removed. The flesh is sprinkled with a little salt and then broiled over charcoal fire and served. Nowadays, electricity and gas are frequently used in place of the charcoal.

3. *Teri-yaki*

Viscera, head, and bones of fish are removed. The fish is then dipped in a mixture of soy sauce and sugar long enough to allow the meat to become soaked with the mixture. The fish is broiled lightly over fire, and again dipped into the mixture. This is repeated until the meat is well done. Tuna and skipjack are often cooked in this way.

4. *Nizakana*

Viscera and/or head and bones are removed. The fish is cooked in soy sauce, mixed with a little sugar. This method, together with "shioyaki," is the most common way of preparing fish.

5. *Mushizakana*

Fresh fish or shellfish is boiled and eaten with a mixture of vinegar, soy sauce, or other seasoning sauce. Sometimes salt, sake (Japanese wine), or soy sauce is sprinkled on the fish prior to the boiling.

6. *Tempura*

A thick mixture of flour, egg, and water (water content 65 to 70%) is prepared separately. The eviscerated fish or shellfish is well covered with this mixture and then fried in boiling vegetable oil. It is served hot and eaten with a dressing made from soy sauce, sugar, or salt. When the fish is oil-fried with the bones and the head remaining, and sometimes the viscera also, the method is termed "karaage." The oil temperature employed is 150° to 200°C.

B. MANUFACTURED AND PROCESSED PRODUCTS

In addition to the above-mentioned methods for preparing fish, a number of fishery products are available, which are manufactured industrially, as frozen, dried, canned, smoked, or salted. It is common practice to remove the salt before cooking. Dried products include those which are directly dried and those which prior to drying have been cooked, broiled, or salted.

1. *Dried Products*

One typical dried product is "katsuobushi." This is skipjack, which, after the viscera, head, and bones have been removed, is cooked in water, peeled of skin, then dried in the flame of burning hardwood for about 40 min. at a temperature of about 85°C. The drying is combined with a standing period, and the process may be repeated from ten to fifteen times. About 20 days is required for completion of the process. The fish is then kept in a special box or barrel closed tightly about 2 weeks for molding. After mold has formed on the surface of the meat, the fish is removed and dried in the sun 1 or 2 days. Such procedure of molding is repeated about four times, requiring nearly 3 months. Through the repeated drying and molding, the product develops a peculiar flavor and taste. *Aspergillus glaucus* is the chief mold used for inoculation.

"Katsuobushi" differs slightly from other dried fish products in its use. It is used chiefly as a kind of seasoning in the form of thin flakes or powder used in preparation of soup. It is rarely eaten by itself. Fish other than skipjack may be used for "katsuobushi," but their products are inferior in flavor and taste. Freshness of fish and contents of fat in the flesh determine the quality of the product.

Another special method is boil-drying, meaning a drying of the fish after boiling a few minutes in water. Products of this type ("niboshi") are peculiar to Japan and are hardly seen in any other Eastern countries, or in Southeast Asia. The boiling prior to drying can be regarded as a measure to kill spoilage bacteria. Another advantage is the release of water followed by the coagulation of the muscle protein. Fish treated this way dry faster than nonboiled fish. Both sardines and anchovies are processed predominantly into such boil-dried products.

Another dried product is "asakusanori" or laver known to exist as early as the sixteenth century. The seaweed is dried in paper-thin sheets. It is mostly cultivated nowadays. Good-quality laver contains 30% protein and 15% carbohydrate on a moisture-free basis.

2. *Kamaboko*

"Kamaboko" is a steamed fish paste. It is made by grinding fish meat and adding salt and sugar as seasoning. The product is finally steamed and molded in varying shapes. Sometimes it is baked. Starch may also be added to the fish meat. It is sometimes erroneously called fish cake in Western publications; fish jelly would be more appropriate. This product is chiefly made from croaker, lizard fish, and conger eel.

3. *Sausages*

Fish sausages were mentioned earlier and are a relatively new product. This industry started as late as 1954, but the annual output now exceeds 400,000 metric tons. The manufacturing process corresponds closely to that of "kamaboki." The grinding and kneading process is similar. The chief difference is in the choice of raw fish. Even such pigment-rich fish as tuna, albacore, and black marlin may be employed and are even favored for this purpose, as their pigments render a meat-like appearance to the product. Whale meat is also used in the making of fish sausages.

Large-sized manufacturing plants have a daily output of more than 300 tons of such sausages per day.

4. *Whale Meat*

Whale meat is processed in Antarctic waters on board factory ships. Approximately 30,000 tons of both lean and fat meat are frozen in slabs (30 kg.) and sent back for further processing.

5. *Canned Products*

The leading canned products are tuna and skipjack. Half of the pack is exported. Albacore is referred to as white meat tuna; all others, including yellowfin, bluefin, and skipjack, fall into the light meat category.

Canned Pacific saury has been developed since the 1950 season. Two packs are available—with and without tomato sauce.

Canned Pacific are frequently packed with vegetables and sometimes seasoned with soy sauce and other flavoring matter. Ginger, red pepper, and certain condiments are commonly used spices in canned fish, and such products are served as a side dish to a rice meal.

6. *Salted Products*

A specially salt-dried fish is "kusaya." This brine has old traditions and is never completely removed, but stored from year to year. Both hard and light salted products are available.

7. *Specialties*

There are many kinds of seasoned seafood products such as "tsukudani," "tsukemono," and "skiokara."

"Tsukudani" is a preserved product made of small fishes or shellfish cooked for a long period in soy sauce with much sugar. There are many kinds of "tsukemono." The cooked fish is subsequently preserved in "miso," rice bran, sake wine, or vinegar. This product is also manufactured industrially (150,000 metric tons per year).

"Shiokara" is rich in nutrients. Salt is added to a mixture of the viscera, muscle, and ovary of fish or shellfish. The mixture undergoes autooxidation or fermentation, thus giving a unique taste. It is frequently made from squid or sea urchin. From the former, the liver and muscle are used with salt and mold (*Aspergillus oryzae*) and from the latter the ovaries, rich in vitamin A, are used.

CHAPTER 9

Fish Meal and Condensed Fish Solubles in Poultry and Livestock Feeding

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I. Introduction

> ". . . they accustom their cattle, cows, sheep, camels and horses to feed upon dried fish . . . of a small kind which they take in vast quantities during the months of March, April and May; and when dried they lay up in their houses for food for their cattle."
>
> MARCO POLO

From the earliest times, fishermen along the seacoasts have been farmers, and waste fish have been used for livestock feeding in many parts of the world where large quantities were available. According to Fielding (1918), it was common practice in the Malay States for fish to be used both as fertilizer and as feed for pigs. Likewise, in the Shetland Isles and on the west coast of Scotland surplus fish were fed to sheep and to pigs. In the first bulletin published by the United States Fish Commission in 1881, mention is made of fish as feed for cattle. In a letter Isaac Hinckley gives an account of the "fish-eating" cows of Provincetown, Massachusetts. When fishermen were cleaning their catch on the shore, the cows used to crowd about for an opportunity to eat the offal. It was said that cows newly brought to Provincetown would refuse fish and that they were accustomed to it by the addition of minced fish to their feed.

In view of the fact that the value of fish for livestock feeding had been recognized for so long, it seems strange that when the first reduction plants went into operation, the potentialities of fish meal as a feed were largely disregarded. For many years, therefore, fish meal was used principally as a fertilizer and was usually referred to as fish guano. In 1884, Atwater reported the analysis of a sample of fish guano made from salmon offal in Victoria, British Columbia, and made the following comment: ". . . it will be seen that this sample is of unusually high grade. It has indeed higher percentages of both nitrogen and phosphoric acid and is consequently more valuable for fertilizing purposes than any of the samples mentioned in an earlier report. It has also a large amount of fat, which would, with the nitrogenous matter, give it a very high value for food for stock, in case, as is by no means improbable, fish refuse should ever come into use for this purpose."

Woodman (1937), in summarizing the early reports regarding the feeding value of fish meal, credits the Norwegian government with the first large-scale feeding trials carried out in 1892 to ascertain if fish meal was a suitable feed for farm animals. At this time there was also considerable interest in the feeding of fish meal in Germany. The success of the Norwegian and the German experiments resulted in the general use on the continent of fish meal as an animal feed. In the United Kingdom and the United States, in spite of these findings and the growing use in continental Europe of fish meal for animal feeding, such meal continued to be utilized as fertilizer for some years. It was, however, not until after World War I that its use in feeding became an accepted practice.

Early records of fish as feed for livestock dealt mainly with cattle, sheep, and pigs, and similarly the first research into the nutritive properties of fish meal was conducted using these animals. The greater part of fisheries products used in United States feeds today, however, goes into poultry rations, and most of the studies carried out in recent years on the nutritive properties of fish meals and other fisheries products have been in connection with poultry and, to some extent, hogs. The emphasis in the following will, however, chiefly be on the use of fisheries products in poultry feeding. In ruminants, such as cattle and sheep, fish meal and solubles are less important as protein sources, and their favorable influence on growth and milk production is ascribed mainly to the stimulating effects of vitamins, minerals, and other accessory substances on the microbial activities of the rumen. No detrimental effect on the milk or butter produced has been established when these fishery products are supplied to the ruminants in reasonable quantities (Breirem, 1951).

II. Fish Meal—General Considerations

A. OVER-ALL VALUE AS FEED SUPPLEMENT

Much of the data available on the nutritive value of fish meals is difficult to assess because it is based on experiments conducted when nutrition was only a rudimentary science and most of the vitamins had not yet been discovered. This is particularly true of studies on the feeding of fish meal to poultry prior to the synthesis of riboflavin and the subsequent availability of this vitamin for use in feeding trials. In drawing conclusions from the literature regarding the nutritive value of fish meal relative to other protein concentrates and the relative merits of fish meals produced from different types of fish and by different manufacturing procedures, it is, therefore, important that careful consideration be given to the nutrients supplied by the basal diet employed.

In present days, with a detailed knowledge of nutrition available and an appreciation of the number of essential nutrients and the interactions among the many nutrients, there can hardly be a general statement of the value of any natural product when a variety of nutrients is involved. The amount and availability of protein, energy, vitamins, and minerals present in the product, as well as the composition of the remainder of the diet of which the product is to be a part, all have to be taken into consideration in any evaluation of nutritive worth. A distinction used to be made between animal and vegetable protein, with the former assumed to be of higher nutritive value. The emphasis on the importance of animal protein as an essential dietary constituent grew out of the fact that, before the development of adequate processing methods for vegetable protein concentrates, it was extremely difficult, if not impossible, to compensate for the amino acid deficiencies in the cereal protein of the ration without recourse to some protein derived from animal sources. Furthermore, animal protein concentrates supplied vitamins which were short in the vegetable protein concentrates. This is particularly true with regard to vitamin B_{12}. With the advances that now have been made in the processing of the various oil seed meals and the rapid development of synthetic processes for manufacturing vitamins and amino acids, the formulation of feeds is based more and more on the analysis of feedstuffs for all the nutrients. The factors determining whether a given product is used or not no longer depend on whether they happen to be of plant or of animal origin, but rather on the particular nutrients supplied by the product and their relative cost from respective sources. Actually, the use of fish meal and condensed fish solubles constitutes one of the few exceptions to this practice because of evidence of the presence of substances which are necessary for maximum growth rate and hatchability in poultry but which have as yet to be termed unidentified factors.

A good general review on fish meals, covering the composition of various types of fish meal and their use in animal feeding, was presented by Breirem (1951) for Norway, by Nehring (1956) for Germany, and by Woodham (1958) for the United Kingdom. United States fish meals, made from ocean perch, herring, menhaden, and whiting, were analyzed in a nation-wide research project (Carver, 1957).

B. Nutrients

1. *Protein*

Fish meal is purchased on the basis of its protein content. This is commonly calculated from the total nitrogen content on the assumption that the protein contains 16% nitrogen. The buyer is assured only of the stated minimum level of crude protein in the meal with no account being taken of the amino acid composition of the protein, its digestibility, or the amount of nitrogen present in compounds other than proteins. Over the years, many testing methods have been proposed in an attempt to increase the information available beyond the bare guarantee of minimum protein level. Biological tests provide the best measure of protein quality but tend to be too expensive and time-consuming for routine testing. Likewise, when they are used for routine testing, microbiological analyses for the essential amino acids present difficulties. Microbiological analyses have to be carried out on hydrolyzates of the protein material, and the method of hydrolysis has a definite bearing upon the results obtained. Unless the hydrolysis is comparable to that occurring *in vivo*, there is no assurance that amounts of amino acids found to be present in a given protein concentrate are available to the animal.

Ford (1960) has developed a microbiological method for assessing the nutritional value of proteins using a strain of *Streptococcus zymogenes*. This microorganism is strongly proteolytic and grows quickly using intact protein as the principal source of nitrogen. Estimates of the quality of proteins from several sources are reported to correlate closely with those obtained using rats.

From time to time, various chemical procedures are suggested for giving a rapid estimate of protein quality. Procedures based on the percentage of protein hydrolyzed in *in vitro* digestion with pepsin, i.e., the percentage of digestible protein, the amount of nonprotein nitrogen and the amount of copper-precipitable protein have been worked out. Almquist (1941) developed a procedure to measure a Protein Quality Index which was used by several investigators. This method involved the determination of the nonprotein nitrogen, the indigestible protein, the copper, and the phosphotungstic acid precipitable fractions and the hot-water-soluble fraction of the protein. The method showed quite good correlation with the results of chick growth tests in evaluating the relative protein supplementary value of animal protein concentrates. The procedure did not find wide acceptance because it was applicable only to animal protein concentrates of the fish-meal and meat-meal type. As yet, there is no satisfactory chemical procedure that has general application for routine testing of all types of protein concentrates for nutritive quality.

Biological tests, which should give the most accurate appraisal of quality, have to be designed to give a specific answer to a clearly formulated question. It is not possible to carry out a test which will indicate the performance of a protein under all conditions. Many of the discrepancies noted between the results of the work carried out in one laboratory and another are referable to differences in assay procedure and particularly to differences in the basal diets used. Even when nitrogen balance studies are undertaken to measure the quality of the protein fed, the results do not necessarily provide an estimate of the quality of the meals as protein supplements. From what is known today, it is possible that the diets used in earlier experiments were not balanced as to energy content and vitamin level. Since both the energy and vitamin content have to be so balanced in the diet as to obviate the effect of energy and vitamins supplied by the fish meal in question, it is difficult to be sure that differences obtained in many of the experiments reported in the literature have been due to differences in the protein quality and not to some other nutrients supplied by the fish meal.

Heiman *et al.* (1939) evaluated protein concentrates on the basis of the response of chicks to diets containing 8% protein from cereal sources and 3% from the protein concentrates and expressed the results as a "gross protein value" relative to the response obtained with casein within the same experiment.

Grau and Williams (1955), in an investigation of the quality of commercially produced fish meal from the standpoint of their value as amino acid sources for chicks, used them in test diets to supply 20% crude protein. In this assay procedure, the vitamins, minerals, and carbohydrate were supplied in purified form so that the diet was entirely dependent upon the fish meals as sources of amino acids, and no data on the values of the meals as vitamin and mineral sources were obtained. The method does not differentiate among various meals as sources of amino acids for the supplementation of other proteins. Striking differences were encountered between fish meals (15 samples) in a chick study designed to assay the dietary protein value (Hinners and Scott, 1960).

The protein quality of fish meals has been evaluated in terms of their value as supplements to cereal or potato proteins in diets containing a total of from 17 to 21% protein (March *et al.*, 1949; Tarr *et al.*, 1954; Schiller, 1957). A cereal diet supplemented with 7% whitefish meal provides adequate amounts of supplemental lysine and methionine and cystine (Evans, 1959). For further discussion, see also Chapter 2 of this volume.

In estimating the value of fish meals as supplements in rations, it would seem that a more critical and meaningful test would be one in which fish meal is used to supplement a cereal or cereal mixture in accord with actual practice in feed formulation. An efficient balance of amino acids in a protein to be used as a sole source of protein in a diet will not be the same as in a protein used as a supplement to other proteins.

Nor are the needs of the animal necessarily satisfied by supplementing the minimum requirement of each of the essential amino acids in the ration. Harper (1956) has reviewed some papers that have appeared regarding the effects of imbalances and excesses in the amino acid composition of the diet. It may be remarked that the effects of imbalances of amino acids are much more apparent when the diet fed is low in protein content than when it contains a high level relative to the requirements of the animal. Besides the implications with regard to biological assay of protein quality, this means also that in commercial practice, where protein represents one of the more expensive portions of the ration and is seldom used in excess, it is extremely important that the amino acids should be in correct balance in order to achieve optimum effect.

Even though tyrosine does not constitute one of the essential amino acids, it is, nevertheless, important in many respects, chiefly due to the fact that the requirements for phenylalanine become greater when tyrosine is low or missing. Comprehensive study of United States fish meals in this respect (Lyman *et al.*, 1958) indicated values between 2.9 and

3.8% of tyrosine crude protein. The amino acid analyses of a variety of fish meals and fish solubles derived from different sources and analyzed in different laboratories are shown in Table I.

2. *Fat*

A high fat content in fish meal has generally been considered to lower the value of the meal for feeding purposes. Early studies (Allardyce *et al.* 1933), showed that growth was depressed in chicks fed fish meals of high fat content. Until comparatively recently, it was generally believed that poultry had a lower tolerance for fat than other animals. It is known now that poultry utilize fat efficiently provided that the diet fed has the correct ratio of protein to caloric content and is adequately fortified with vitamins. Accordingly, the fat content in a fish meal may contribute to the over-all nutritive value of the product. There is not a great deal of information available regarding the nutritive value of fat derived from fish meal, and research conducted so far has not provided a conclusive answer.

It is known that the ether-soluble fraction in fish meal gradually decreases, due to oxidation and polymerization, into less soluble compounds (Oshima and Sugawara, 1936; Takano, 1937; Harrison, 1939a; Stansby and Clegg, 1955; Almquist, 1956). The large surface area presented by fish meal facilitates oxidation of the oil present. The chemical constitution of the oil itself is such that it is readily oxidized. A report from Norway (Aure, 1957) gives the iodine value of oil extracted from herring meal as 136 as compared with a value of 123 for the herring oil produced in the reduction of the herring. He explains the difference between the values for herring oil and the oil extracted from the meal as being due to a concentration of phosphatides in the meal-fat, the fatty acids of which are more unsaturated than herring oil fatty acids. In addition to the susceptibility of the oil content of the meal to oxidation, the presence of hematin in the meal catalyzes the process. Banks (1939) showed that hematin accelerates rancidity in the oil content of fish tissue, and more recently it was demonstrated (Anonymous, 1958c) that the content of hematin is a major factor in determining the rate at which fish meals deteriorate.

Whether oxidized oils are deleterious in feeding or not has occasioned a great deal of research (Matsuo, 1954). Studies with rats have shown that oxidized and polymerized oils seem to contain toxic factors as well as being poorly digested (Lassen *et al.*, 1949a; Fraser *et al.*, 1949; Crampton *et al.*, 1951). The exact nature of the apparent toxicity is not altogether clear. Crampton and his associates have made an extensive

TABLE I

AMINO ACID CONTENT OF FISH MEALS AND FISH SOLUBLES[a]

Fish meals and solubles	Reference No.	Arginine	Histidine	Lysine	Tyrosine	Tryptophan	Phenylalanine	Methionine	Cystine	Threonine	Leucine	Isoleucine	Valine	Glutamic Acid	Glycine
Herring	1	6.1	2.2	10.4	2.6	0.7	3.6	2.2	—	3.9	8.9	4.6	5.6	—	—
Herring	1	6.6	2.1	12.2	3.3	0.6	3.6	2.4	—	3.3	5.9	4.6	4.8	—	—
Herring	2	7.6	1.9	5.1	0.6	0.1	2.7	2.8	—	3.3	4.2	1.9	3.0	—	—
Herring	3	5.7	2.4	8.2	—	1.6	4.0	2.9	—	4.5	8.2	5.7	6.0	—	—
Herring	4	8.1	2.1	9.1	3.3	0.8	3.9	2.7	1.6	4.2	7.6	6.7	5.8	12.0	5.7
Menhaden	5	6.4	2.6	8.7	2.6	1.1	4.3	3.0	—	4.8	8.2	4.6	5.8	—	—
Sardine	6	7.4	2.4	7.8	4.4	1.3	4.5	3.5	1.2	4.5	7.1	6.0	5.8	—	—
Sardine	3	5.9	2.6	8.6	—	1.3	4.3	3.0	—	4.4	7.8	5.1	6.0	—	—
Salmon offal	2	8.3	2.6	11.4	2.9	0.9	4.4	2.6	—	5.1	9.2	5.5	6.3	—	—
Salmon viscera	2	7.3	3.1	7.9	1.9	1.1	5.1	3.3	—	5.2	10.7	8.4	6.6	—	—
Whitefish	3	6.5	1.8	6.8	—	1.0	3.4	2.6	—	4.1	6.6	4.1	4.5	—	—
Whale	3	4.7	2.2	6.6	—	1.6	3.9	1.9	—	3.1	8.1	5.2	5.3	—	—
Crab	3	5.5	2.0	4.6	—	1.1	4.2	1.8	—	3.8	6.5	4.4	5.0	—	—
Crab	7	5.7	1.5	4.6	—	1.1	4.9	1.8	—	3.4	5.7	3.7	4.9	—	—
Shrimp	3	5.3	1.7	4.8	—	0.9	3.7	1.7	—	3.5	5.4	3.7	4.7	—	—
Herring scales	2	7.6	1.9	5.1	0.6	0.1	2.7	2.8	—	3.3	4.2	1.9	3.0	—	—
Pollock scales	8	8.8	1.6	4.4	2.3	0.5	2.7	1.8	0.5	4.1	3.5	2.5	3.4	10.6	37.6
Condensed solubles															
Fish	2	3.5	1.1	4.5	0.6	1.9	2.0	1.6	—	2.0	4.1	3.6	2.6	—	—
Herring	4	5.2	0.7	4.3	0.7	0.1	1.5	1.4	0.1	2.1	3.2	1.9	2.5	7.5	10.9
Menhaden	9	4.5	2.0	4.6	0.7	0.5	2.0	1.6	—	2.2	3.1	2.0	3.0	—	—
Sardine	10	4.3	5.8	4.9	—	0.4	2.3	1.5	—	2.4	4.7	2.7	3.0	8.4	6.7
Whale	10	6.8	1.0	4.0	—	0.5	—	1.4	0.1	—	3.4	—	3.7	7.4	—

[a] Calculated to 16 g. nitrogen.

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study of the effects of heat treatment of various oils on the nutritive qualities of the oils. It was concluded (1951) that in the case of linseed oil, peroxidation is not concerned with the development of any toxic factor and that the damaging factor in heated oil is not produced oxidatively. Further studies (1953) showed that the toxicity of heat-polymerized linseed oil was associated with the presence of polyene acids in the original oil. Johnson *et al.* (1957) found that thermally oxidized corn oil inhibited growth when fed to rats, whereas margarine base stock and butter which had been heated under similar conditions gave only a slight growth depression or did not depress growth. Again it appeared that products resulting from the thermal treatment were related to the unsaturated fractions of the oil. Witting *et al.* (1957) found that the toxicity of oxidized and oxidatively polymerized fish oil produced by blowing with air for three days at room temperature was less than that of oil thermally polymerized without oxidation. When the oils were fed to rats, it was noted that the harmful effects of the oxidized oil could be more easily offset than those of the thermally polymerized oil by an increased intake of pyridoxine, riboflavin, or protein. Biely *et al.* (1951) concluded, on the basis of experiments in which a low-temperature dried herring was subjected to various treatments, that the adverse effect of overheating on the nutritive value of herring meal was in part due to changes induced in the oil. Heating of the specially prepared meal for 2 hr. at 300°F. impaired its nutritive value, but similar heating of a sample of the meal from which the fat had been extracted with hexane was without deleterious effect. When the oil present in the heated, unextracted meal was heated and added to the extracted meal, the nutritive value of the latter was impaired, whereas similar addition of fresh herring oil had no undesirable effect. As in the findings of Witting *et al.* (1957) mentioned above, further experiments showed that the growth depression occurring when the hexane extract from herring meal was fed to chicks could be counteracted by increasing the vitamin content of the diet.

March *et al.* (1960) reported that storage of herring meals for up to 9 months did not alter their nutritive value as protein or vitamin B complex supplements in chick diets despite marked decreases in both ether extractability and iodine value of the extract. Later experiments (March *et al.*, unpublished data) showed that the feeding of chloroform-methanol extracts of herring meal, in common with herring oil, depressed growth of chicks fed a vitamin-deficient diet. The growth depressing effect of the fats was, however, overcome completely when the diet was supplemented with vitamins. The actual utilization of the lipid fraction of freshly manufactured herring meal was found to be approximately 80% that of herring oil.

The entire problem of the nutritive effects of the polymerization of fish oils is discussed in Chapter 3 of this volume. One essential observation pertaining to hogs will be brought out here. Oldfield *et al.* (1957) observed that pigs fed 5% of either crude or alkali-washed menhaden oil gained weight at a faster rate than did the pigs on a control ration. Those fed polymerized menhaden oil gained weight less quickly than did the controls. The carcass quality of the pigs fed the polymerized oil, however, was superior to that of the pigs fed either of the other types of oil and was similar to that of the controls. From this trial it seems possible that a fish oil polymerized under carefully controlled conditions might yield a product satisfactory from the nutritional as well as the carcass quality standpoint (Oldfield *et al.*, 1957).

Old samples of fish meal may contain as much as 40% of free fatty acid in the oil, according to Moen (1933). It is doubtful if a high free fatty acid content in fish meal is, in itself, harmful since pure fatty acids may be fed to chicks without depressing growth (Sunde, 1956). With meat scraps, it has been found that no ill effect results from feeding samples high in free fatty acids (Gray and Robinson, 1941). Siedler *et al.* (1955) concluded that animal fats that vary in free fatty acid content are utilized equally well by the chick. It seems probable that the fat content of the fish meal may exert an indirect effect on the nutritive value of the meal through the activity of peroxides in destroying vitamins in the fish meal itself, or in mixed rations to which the meal may be added.

The darker color noted in some samples of fish meal is apparently due, in part, to reactions between the protein and the oil at the carboxyl and amino groups, oxypolymerization and oxidation of unsaturated oils according to Venolia *et al.* (1957). Lea *et al.* (1958) found that defatted meals did not darken upon storage, nor did intact meals when they were stored in an atmosphere of nitrogen. Venolia *et al.* showed that emulsions of menhaden oil and protein react to form a deep brown color. Oya and Nonaka (1938) showed that fish oils adsorbed on sardine meal and other protein for 30 days and then removed were darkened by contact with the protein. They noted that adsorption on nonprotein material did not give the same darkening. That the darkening of the fish meal is an indication of a reduction in the amount of utilizable lysine in the fish meal has been shown in studies conducted by Lea *et al.* (1958). The results of the latter investigation will be discussed in more detail in the section relating to the effects of storage on the nutritive quality of fish meal.

3. *Minerals*

The mineral content of fish meal will vary depending on the raw material used. Scrap from a filleting operation, for example, because of the high bone content, will yield a meal of much higher mineral content than will whole fish. The principal minerals supplied are calcium and phosphorus. Since they are in a form available to the animal, the levels of these minerals which have to be supplied from some other source such as bonemeal or calcium phosphate may be reduced in a ration containing fish meal. Iron, magnesium, potassium, and sodium are, of course, present. As would be expected, since it is a marine product, fish meal is also a good source of trace minerals. Newell and McCollum (1931) analyzed spectrographically different types of fish meal and found aluminum, barium, chromium, copper, lead, lithium, manganese, and strontium in all of the meals, with fluorine, nickel, silica, silver, tin, titanium, zinc, and barium present in some of them. The iodine content of fish meals is worthy of note in view of the fact that the distribution of this element in other feedstuffs is rather limited. Wells (1924) reported that sardine meal contains 890 parts of iodine per billion. There is evidence in the literature to suggest that some trace mineral, not yet recognized as being essential, may be responsible for part of the growth response attributed to unidentified factors in fish products (Morrison *et al.*, 1955; Camp *et al.*, 1956).

4. *Vitamins*

In early feeding experiments with fish meals, the fat-soluble vitamins A and D undoubtedly contributed to the biological response obtained to the meals. Whitefish, herring, or sardine meals, when fed as 10 to 12% of a ration, were reported by Dove (1934) to supply sufficient vitamin D to meet the requirement of the chick. Dove also reported on the effect of storage on the vitamin D potency of fish meals. Flame-dried sardine meals after 8 months storage began to lose vitamin D potency. Vacuum-dried meals were superior to flame-dried meals after storage with respect to vitamin D.

Little consideration is given at the present time to the content of vitamins A and D in fish meal. Because of the temperatures used in processing and the oxidation occurring in the fat content of the meal after manufacture, the meals cannot be considered a reliable source of vitamins A and D. With vitamins A and D available in fish oils and concentrates of guaranteed potency, the amounts of these vitamins supplied by fish meal are not of any significant importance. Furthermore, there is a basic difference between meal from fatty fishes as compared to those from lean fishes. Isaachsen *et al.* (1926, 1927) reported that cod meal caused rachitis in pigs, but herring meal did not.

Fish oils have been found to contain some vitamin E, but fish meals cannot be considered as sources of vitamin E in animal feeding. On the contrary, fish meals, rich in oil, frequently require additional quantities of vitamin E. Cod liver oil, as well as other fish oils with a high degree of unsaturation, easily aggravates the symptoms of vitamin E deficiency, such as exudative diathesis and encephalomalacia in chickens. The addition of from 0.5 to 1.0% of a highly unsaturated fish oil to a diet low in vitamin E is sufficient to induce encephalomalacia. This effect of unsaturated fats, particularly fish oils, has been demonstrated with many species of animals. Adequate amounts of vitamin E in the diet prevent the occurrence of such disorders (Singsen *et al.*, 1955; Moore *et al*, 1959). Investigations in this field tend to indicate that the cause of encephalomalacia primarily is the peroxidation of the highly unsaturated fatty acids, which sufficient quantities of vitamin E are capable of preventing. Indirect evidence of this is the fact that good protection against this disorder also may result from adding an antioxidant diphenyl-*p*-phenylenediamine (DPPD) incorporated into the chicks' diet (see Bunnell *et al.*, 1956). Later studies indicate that selenium (factor 3) could wholly or partially replace vitamin E as a preventive against exudative diathesis (Schwarz *et al.*, 1957). Vitamin E appears, however, to be needed to counteract the dystrophy-producing effects of fish oils on ewes (Welch *et al.*, 1960). Unlike vitamin E, the selenium compound does not suppress the rancidification of feed fat (Rahman, 1960).

With regard to the remaining fat-soluble vitamin, vitamin K, also known as the antihemorrhagic vitamin, Almquist *et al.* (1935) found that putrefied fish meal was a good source of vitamin K. McKee *et al.* (1939) prepared vitamin K_2 by allowing moist fish meal to undergo bacterial putrefaction. Lanham and Nilson (1942) also reported that the vitamin K content of sardine meal was increased when the meal underwent experimental spoilage with heat and moisture. Normal fish meal, as opposed to spoiled meal, is not a good source of vitamin K. In fact, diets using herring meal as protein supplement have been used by Davies *et al.* (1958) to promote vitamin K deficiency in chicks.

Interest in the vitamin content of fish meals was, in the first instance, directed towards riboflavin, then to vitamin B_{12}, and currently to the existence of one or several unidentified factors. Some data with respect to the content of water-soluble vitamins in fish meal are given in Table II. It will be seen that the amounts of several vitamins of the B complex are considerable and should not be disregarded in assessing the

TABLE II
Vitamin Content of Fish Meals and Fish Solubles[a]

Fish meals and solubles	Reference no.	Vitamin B_{12} (mμg./g.)	Riboflavin (μg./g.)	Thiamine (μg./g.)	Nicotinic acid (μg./g.)	Pantothenic acid (μg./g.)	Pyridoxine (μg./g.)	Choline (μg./g.)
Anchovy	1	120	4.2	—	37	—	—	—
Herring	1	250	5.9	—	55	—	—	—
Herring	2	350*	—	—	—	—	—	5096
Herring (whole)	3	—	11–12	—	—	—	—	—
Mackerel	1	350	4.8	—	54	—	—	—
Menhaden	1	—	3.3	—	54	—	—	—
Pilchard	2	200*	—	—	—	—	—	—
Sardine	1	210	3.5	—	53	—	—	2830
Sardine	4	400	9.0	1.2	47	—	31.1	2600
Salmon	5	180–360*	—	—	—	—	—	—
Tuna	1	270	6.0	—	127	—	—	—
Whitefish	6	120	13.5	3.9	46	11.8	11.2	—
Whitefish	6	120	5.9	2.5	44	5.6	2.7	4000
Whitefish	5	80*	—	—	—	—	—	—
Crab	1	—	7.0	—	33	—	—	—
Whale meat	1	60	8.0	—	97	—	—	—
Whale meat	7	40	8.0	1.3	96	2.5	8.3	—
Whale liver	7	500	77.0	3.0	200	36.5	9.5	—
Condensed solubles								
Fish	7	330	8.0	2.9	120	21.6	11.4	—
Herring	5	670*	—	—	—	—	—	—
Menhaden	5	300*	—	—	—	—	—	—
Sardine	5	460*	—	—	—	—	—	—
Sardine	8	—	20.0	4.0	325	40.0	—	—
Whale	8	—	1.5	—	22	10.6	—	—
Whale	5	320*	—	—	—	—	—	—

[a] Calculated on a wet-weight basis except where marked with asterisk to indicate calculation on a dry-weight basis.

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nutritive value of fish meals. The vitamin content of fish meals may vary considerably according to both the raw material and the processing procedure. The various factors involved are discussed later under the appropriate headings in several of the following sections.

As a whole, fish meal is superior as a source of B vitamins compared to other common animal feeds (Nehring, 1956). Almost half the monetary value of fish meal can be attributed to the protein and "extra" methionine provided by fish meal. Energy, phosphorus, and growth factors also make substantial contributions, but the particular value of yet unidentified growth factors makes fish meal still more attractive as a food (Bird, 1958).

C. FISHY OFF-FLAVORS IN EGGS AND MEAT

The problem of fishy flavors in eggs and in poultry meat and pork and the extent to which fishery products used in feeding are responsible for fishy off-flavors is a recurring one.

So-called "fishy" eggs are not usually the result of feeding high levels of fish products in the laying ration (Dunn, 1956). Vondell (1933) attempted to produce fishy eggs by feeding fresh fish to hens. He found that even hens which were fed fresh fish daily did not produce fishy eggs. Neither did fish meal at 4 to 15% of the diet result in fishy eggs. Tepper *et al.* (1939) reported that no off-odor or flavor was evident in eggs or meat from birds fed 13% fish in the ration.

There may, on the other hand, be some production of fishy eggs from hens which receive neither fresh fish nor fish meal in the ration. Accordingly, it seems that the production of fishy eggs is the result of a hereditary trait, since it shows a higher frequency in closely related strains of birds (Vondell, 1933). The inclusion of a high level of fish oils used as supplements for the purpose of supplying vitamins A and D is too low, however, to be a factor in this regard (Almquist *et al.*, 1938). Unless the fat content of fish meal is considerably in excess of the average, fish meal may be fed even in large amounts and gives no taste or odor to eggs laid by hens to which it is fed. Robertson and Wilhelm (1940), on the basis of tests in which salmon meal was fed at as high a level as 28% in the ration, concluded that the production of fishy eggs cannot be blamed on feeding fish meal. A study conducted by Gasperdone *et al.* (1960) showed that the feeding of an excessive amount of fish meal to certain strains of laying birds could result in the production of off-flavored eggs.

As in the case of eggs, meats with fishy flavors have been reported that could not be attributed to the feeding of fishery products. Odland *et al.* (1955) reported some fishy flavors in broilers not fed fish by-products as supplements. Klose *et al.* (1951), in connection with studies on dietary fat and quality of turkey meat, showed that fishy flavors can be produced by feeding a highly unsaturated oil such as linseed oil. As a whole, turkeys are more susceptible to the influence of fish products in the diet than are chickens and duck. A definite species difference prevails (Dunn, 1956).

Fishy flavors may be evident in turkey and chicken meat when fish oil or high levels of fish meal are fed. In the latter case, however, flavors would appear to be the result of the oil content of the fish meal. For example, Almquist *et al.* (1938) state that the feeding of fish meal will not result in off-flavors in poultry meats unless the fat content of the fish meal is exceptionally high. There are, nevertheless, quite a few reports in which fish meal feeding has been implicated in fishy flavors in poultry meats. Bryant and Stevenson (1939) and Marble *et al.* (1938) demonstrated fishy flavors and odors in turkeys fed fish meals and showed that, when 10 to 20% fish meal had been fed, a period of 4 to 8 weeks was required during which all fish meal had been omitted from the ration in order that all traces of fishy flavor were removed. The length of time required before all fishy flavor disappeared depended upon the level of fish meal that had been fed. Van Santen (1957) claims that the customary practice of discontinuing fish meal feeding 6 weeks before slaughter is no safeguard against fishy taste and smell, which may be obvious after 4 months.

A report with respect to ducklings (Nilson, 1946) states that in 6-week-old battery-fed birds which had been fed high levels of fish meal, the flesh showed no fishy or other off-flavors.

Discrepancies between the findings of different investigators have probably been due to differences in the quality of fish meals tested and in the handling of the birds prior to and after slaughter. In the majority of cases, unfavorable results have been obtained when over 2% of fish oil has been fed. The feeding of high levels of fish meal might likewise be expected to have an adverse effect on palatability, depending on the fat content of the meal. Asmundson *et al.* (1937), for example, found that turkeys fed inferior-grade sardine or tuna meals had a poorer flavor than those given the high-grade meals. The effect of the low-quality fish meals is doubtless due to the rancid state of the oil in the meal, since it is recognized that the quality of the fat which an animal receives has a bearing upon the flavor of the meat. Callow (1939) found, e.g., that in the case of hams the yellow color and fishy flavor were worse from pigs fed low-grade cod liver oil than with high-grade oil. All fish oils do not behave in the same way. Redfish oil seems to be less dangerous than others (Dunn, 1956). Asmundson *et al.* (1937) observed that high-grade fish meal apparently did not produce an off-flavor in turkeys when the birds were properly handled prior to and after killing.

In many countries it has been well established, both through experimentation and practical experience, that fish meal, solubles, and silage all constitute excellent feed supplements (Kirsch *et al.*, 1943; Hansen, 1959; Pecht, 1954). Extensive studies of the effect of fish oil on depot and body fat of hogs have been reported by Dahl (1957). These investigations clearly bear out that specific unsaturated fatty acids accumulate in the body with an ensuing lack of stability and proneness to oxidize readily. This causes off-flavors. These findings explain the recommendations given as to the use of fish and fishery products as a high-quality protein adjunct in hog feed: the total fat content should be low, feeding of such products should terminate at a time sufficiently early in relation to slaughtering time to remove any risk of such labile constituents dominating the fat composition (Hansen, 1959). Such fish products may, however, without causing deleterious effects, be used in the raising of breeding hogs. In order to avoid appetite disturbances, acid silage should be partially neutralized, so that pH exceeds 3.5. In Swedish experiments with fattening hogs, no differences in the growth curves were observed when the animals were fed skim milk, fish meal, or fish silage (Olsson and Olofson, 1955).

D. INFECTIONS

The possibility of fish products conveying diseases has been clearly recognized by fur breeders. Diarrheas and other symptoms have frequently been traced to fresh or frozen fish products.

In recent years, there are several reported cases from West Germany and Netherlands where salmonellas have been carried by fish meal to hogs and poultry and secondarily also to man (Mossel *et al.*, 1958). According to Grimbergen (1959), Dutch fish meal was far more incriminated than any imported meal. For a comprehensive analysis of this problem, the reader is referred to Part I of Chapter 11, of this volume.

III. Factors Affecting the Nutritive Value of Fish Meal

A. RAW MATERIAL

1. *Kind of fish*

It is rather difficult to generalize with respect to the relative nutritive value of fish meals made from different kinds of fish. The manufacturing procedure varies with the kind of fish. Thus, with fish of high oil content, the process applied for extraction of the oil will have a bearing upon the protein and vitamins in the remainder of the fish and may also determine the practical means of drying the residues for the production of a meal. The kind of fish will also affect the composition of the final product, not only because of differences in the over-all composition of the whole fish, but because of differences in the proportions of various tissues which are utilized in products for human consumption and those which represent waste and provide the base material for meal. Furthermore, because of variations in the quality of fish meals, even among those made from the same type of fish and by the same general procedure, it is necessary to study a great number of samples before drawing general conclusions regarding any type of meal.

Fish meals have been divided into two main classifications: oily meals, which are made from fish in which the body fat is distributed throughout the body; and nonoily meals, in which most of the body fat is concentrated in the liver. At one time oily fish meals were regarded as inferior to nonoily meals for feeding purposes. Woodman, as recently as 1937, describes herring meal as a product used almost entirely as a fertilizer in Great Britain. With modern methods of processing, the distinction in quality between fish meals according to whether or not they may be classified as oily or nonoily is today no longer applicable.

Differences among species in the composition of the flesh itself are not responsible for any appreciable differences in the protein quality of meals processed from different kinds of fish. Nilson *et al.* (1947) fed acetone-extracted fish flesh from 17 species of fish to rats in a basal diet containing some supplementary protein. From the growth rates of the rats, it was concluded that the proteins were about equal in nutritive value. Konosu *et al.* (1956) found that the amino acid composition of fish muscle proteins was relatively constant without distinction among species. Differences among meals from different sources would seem to be influenced more by the nature of the method of manufacture, especially the extent to which the vitamins might be lost through leaching or destroying by overheating than by the kind of fish.

Fish meals made from some kinds of fish are more variable than others in nutritive quality. Meals from whole fish might be expected to be more uniform than meals made from the scrap and trimmings of fish processed for human consumption. Differences in processing, however, result in considerable variation among fish meals derived from similar raw material.

Whitefish meal, like the meals made from any of the white fish such as cod, haddock, cusk, hake, sole, or halibut, may vary in quality, not because of any species differences in the amino acid composition of the body proteins, but because of differences in the relative amounts of muscle, heads, skins, and viscera that may provide the raw material for a given batch of meal. Differences among species in the composition of the flesh itself are not, as mentioned above, responsible for differences in the protein quality of meals made from different kinds of fish. Scrap meals, when made from more than one kind of fish, may also vary from one lot to another because of processing difficulties associated with material of this nature. If the raw material is to be processed for its oil content, the cooking time has to be carefully regulated, since some types of fish require more cooking than others for the maximum yield of oil. As a result, when a mixture of tissue, some of which is more refractory than the rest, is processed, some of the material is apt to be overcooked, with subsequent loss of protein and vitamins into the press water.

The sand launce is extensively used for fish meal by the Danish fish industry. It is primarily in the latest decade that this fish has become important in this respect. Earlier, it was chiefly used as bait. It is well adapted to the production of fish meal, and several thousand tons are manufactured each year.

French scientists report no difference between good-quality meals of Norwegian herring and Moroccan sardine being employed in poultry raising (Ladrat *et al.*, 1958).

Tuna meal seems to vary considerably, according to the data of Grau and Williams (1955). They tested 17 samples of tuna meal and classified 9 of them as being poor quality when tested as amino acid sources for the chick. MacIntyre (1957) determined the nutritive value of 40 different commercial samples of fish meals produced on the Atlantic coast of Canada. The meals varied in protein content from 51.6 to 69.2% and most of them were from white fish. MacIntyre found that even with meals produced under the same registration number from the same manufacturer, but at different times, there was considerable variation. He considers that "this variation may be due to differences in the nature of the raw material such that similar methods of processing result in meals of different composition or to processing procedures which differ sufficiently to produce differences in the composition of the final product or a combination of both."

Differences in manufacturing methods may explain the controversial results as to the value of carp meal as compared to other fish meals. According to Adams and Carlson (1951), it produced a slower rate of growth than either of two other fish supplements. It was also less efficient, requiring 1.80 lb. of feed to produce 1 lb. of gain. The rations employed contained approximately 22% protein and 950 to 1,000 calories of productive energy. Earlier reports indicated that carp meal was equal to or superior to various other fish meals in promoting growth in chicks.

As carp and other "rough fish" in the United States become available in sizable quantities through the seining from lakes being cleared for more desirable kinds of game fish, it is essential to assess the value of such trash fish as protein supplements. Such fish meal obtained locally is sold at a lower price than other fish meals, as it is transported comparatively shorter distances than fish meal from marine sources. Carp meal seems to produce a slower rate of growth in chicken than other fish meals (Adams and Carlson, 1957). It is also less efficient as to feed conversion.

A new type of meal is made by grinding and steam dehydrating whole trash fish, obtained when shrimping in the Caribbean and off the South Atlantic coast of the United States, such as croakers, blowfish, toadfish, searobins, silver ells, etc. Until recently, these fish were dumped back into the ocean. In tests this type of fish meal turned out to be equal to either menhaden or sardine meal when incorporated into broiler rations on an identical protein level (Anonymous, 1958b).

The vitamin content of meals depends, apart from processing factors, on the relative proportions of different tissues contained in the meal. Record *et al.* (1934) concluded, on the basis of chick tests, that meal prepared from heads and tails contained more riboflavin. There is evidently a difference in the vitamin content of red muscle and ordinary muscle. Mori *et al.* (1956) reported that the red muscle of fish is very rich in thiamin, riboflavin, and vitamin B_{12}, but that it contains less niacin than ordinary muscle.

Besides traditional fish meal, chiefly manufactured from whole fish and discarded portions of filleted fish, chiefly the backbone and head, the Canadians have successfully tried visceral meal made from the entrails of fish. The liver is generally excluded and used for other, more valuable purposes.

The viscera are submitted to an enzymic digestion and thus transformed into a liquid. This is dried on a drum drier, and a coarse powder, dark-cream in color, is obtained. This powder contains most of the original vitamins of the viscera and the proteins in a predigested form. Such visceral meal has no taste of fish. This product has been developed by the Halifax Station and successfully tested for animal feeding purposes. It proved to be a satisfactory protein supplement for use in the rations of hogs during both their growth and their fattening periods.

The test hogs exhibited no objections to such processed "flour" in their rations and showed satisfactory rates of feed efficiency and carcass grade (Anonymous, 1958a).

The fresh viscera of cod and haddock are collected on board ship, preserved with sodium nitrite, and held at 80° to 100°F. (26.7 to 37.8°C.) for several days. During this period of holding, the enzymic digestion takes place.

Although there is a great deal of data available on the amino acid composition and the feeding value of meal derived from the flesh or muscle of fish, there is less information regarding meals from other tissues. Lemack *et al.* (1958) investigated the nutritive value of scales from ocean perch and herring when added to fish meal to contribute 10% of the meal protein. Chick and rat bioassays showed that the addition of fish scales at this level did not affect the nutritive quality of the meal. Snyder and Nilson (1959) reported the biological value of pollock fish scales to be about 60% with about 80% availability, when fed at a 9% level in the diet of rats. The fish scale protein was not in itself adequate for growth but could be utilized as a limited source of protein and contained no toxic substances per se. Ney *et al.* (1950) found that the protein of herring scales was extremely low in tryptophan.

2. *Season*

Seasonal differences in the composition of the raw herring may result in differences in the meals produced. Lovern (1938) found that the iodine number of herring oil may vary from 115 to 144 in fish from the same area at different times of the year. He suggested that in fasting the herring utilizes the more unsaturated constituents of the body fats preferentially. Immature herring had a more saturated fat than adult herring caught at the same period. In this regard, Banks (1952) observed that the fat of summer-caught herring oxidizes and becomes rancid more quickly than that of winter-caught herring.

According to Bissett and Tarr (1954), meals produced from herring caught in February contain more deoxypentosenucleic acid and more total pentose than meals made from herring caught in November (because the February meals contain considerable amounts of practically mature milts). It was found that the tryptophan, methionine, lysine, threonine, and valine contained in the herring meal were more readily rendered unavailable by heat treatment in the case of the February than of the November meals. They suggest that Maillard reaction between liberated pentose sugars and amino acids may have been responsible for the differences observed.

Tarr (1952) observed no difference in the vitamin B_{12} content of meals produced in November or those from herring caught in February.

3. *Spoilage*

Despite the fact that spoilage would seem to be a possible factor affecting quality in fish meal, there is very little information regarding the nutritive quality of fish meal prepared from fresh fish as opposed to fish which have undergone various degrees of putrefaction. What little data there are on the effect of condition of fish used in making meal are contradictory. Ingvaldsen (1929) found that the essential amino acids were destroyed and the proportion of water-soluble nitrogen was increased as a result of spoilage in the raw material. Lassen *et al.* (1951) reported, on the other hand, that spoilage of the raw fish before processing had little effect on the nutritive value of the resultant meal, although there is a much greater loss in the stickwater, so that the yield of meal is reduced. Furthermore, the meal produced contains increasing amounts of oil, thereby reducing the free oil recovered. Although there appeared to be no difference in the quality of the meal produced, the quality of the condensed fish solubles decreased as a result of storage of the raw fish.

Likewise, in the case of mackerel meals, a meal processed from fish that were soft and broken with obvious spoilage was equal in protein value for chicks to one made from firm-fleshed mackerel suitable for canning, according to data of Grau and Williams (1955). Grau *et al.* (1956) made the interesting observation that whereas meal dried from *cooked* fish that were allowed to spoil subsequent to cooking did not permit growth of chicks, meal made from spoiled *raw* fish did permit good growth. Banks (1950), in reporting the results of studies to determine the most favorable conditions for the production of dehydrated herring, gives some data regarding the effect of storage of the fresh fish on the subsequent stability of the dried product which may be pertinent to fish meal processing. In the case of dried herrings, the freshest fish yield the most stable dried product. Cold storage or holding the fish in ice for more than two days before drying reduces the stability of the dried herring.

B. PROCESSING

1. *Wet vs. Dry Rendering*

Record *et al.* (1934) found that wet- and dry-rendered meals were similar in nutritive value according to growth studies with chicks. With rats, however, Wilder *et al.* (1934) showed that the absorbed nitrogen from wet-rendered haddock meal was more efficiently utilized than from dry-rendered meal, probably because of the lower content of water-soluble protein. Harrison *et al.* (1935) reported that the removal of the water-soluble protein by the wet process had little effect on the ultimate efficiency of the protein but decreased the riboflavin content. Because the two processes are generally applied to materials requiring different procedures of manufacture on account of differences in oil content, comparison of meals on the basis of whether they are wet- or dry-rendered is hardly justified.

2. *Whole or Full Meal*

Whole meal or full meal is the name given to fish meal that has had the press water added back to it. On the basis of Almquist's Protein Index scheme of analysis, dried fish press water would not appear to be of high protein value because of the high content of hot-water-soluble protein (Almquist, 1941). This was borne out by the growth response of chicks to blends of dried press water and ordinary fish meal. This is contrary to the results of earlier experiments (Wilgus, 1933a) which showed protein efficiency to be superior in fish meals containing the press water. In view of the data obtained in the latter study, it seems likely that the whole-meal preparation supplied water-soluble vitamins which were a factor in the efficient utilization of the protein. For an accurate appraisal of whole meal from the standpoint of protein quality, only the results of more recent experiments can be taken into consideration.

Since it would be desirable to be able to determine the proportion of stickwater solids in a given whole meal, Norwegian investigators (1950) found that a minimum of 20% of the total crude protein of whole herring meal was soluble in water when all of the press water was added back. It is difficult, however, to determine accurately the amount of solubles added to a whole-meal mixture because the protein of condensed solubles is not entirely soluble and standard fish meals without added solubles contain varying amounts of water-soluble protein (Lee, 1954).

Laksesvela (1958) has reported the results of an extensive study of the nutritive value of condensed herring solubles and herring meal. He found that when fed in the diet as the only source of protein, herring solubles appeared to be of little nutritive value. Certain mixtures of herring solubles with meal, however, were superior to the meal alone as a protein source. Tryptophan was the limiting factor in the herring solubles. When the protein from the solubles represented between 15 and 45% of the total, the biological value of the mixture was raised above that of meal alone, but when more solubles were used in the mixture, growth was depressed. Solubles alone did not sustain life for more than 2 to 4 weeks when fed to day-old chicks. In these experiments the ordinary meal and the solubles originated from the same raw material. The data, therefore, indicate that, while condensed herring solubles is not a balanced source of amino acids for the chick, it may be used to advantage to supplement press cake protein.

In 1941, Billings *et al.* showed that stickwater dried to a meal under vacuum contained twice as much riboflavin as ordinary fish meal. Further work suggested that stickwater might be dried to give a meal rich in riboflavin that could be used as a feed supplement (Pratt and Biely, 1945). Karrick and Stansby (1954) reported that, of the total riboflavin, niacin, and vitamin B_{12} content in the raw material, 59% of the vitamins was in the solubles and 41% was in the meal produced. It follows that whole meals should be richer in the water-soluble vitamins than meals produced from drying presscake without adding back the press water.

3. *Drying Temperature*

Of the various aspects of fish meal manufacture, the one which has perhaps received the most widespread attention is that of drying temperature. This is understandable in view of the vast literature dealing with the destruction of vitamins by heat, the impairment of protein nutritive quality by heat and the lowering of digestibility of fats and even the production of toxic products resulting from heat treatment of fats.

Early work on fish-meal processing (Ingvaldsen, 1929) showed that high drying temperatures increased the volatile basic nitrogen and reduced the arginine and cystine content of the meal. Much of the experimental work on the effects of drying temperature was in relation to the type of drying equipment, i.e., steam or vacuum dryer. In feeding tests with different animals, vacuum- and steam-dried meals were generally reported to be better supplements than flame-dried meals (Maynard and Tunison, 1932; Record *et al.*, 1934; Harrison *et al.*, 1935; Oshima and Itaya, 1938; Daniel and McCollum, 1931; Schneider, 1932; Wilder *et al.*, 1934). Flame-drying, if properly controlled, need, however, not be more detrimental than steam- and vacuum-drying. Only when severe did flame-drying have more than a trivial destructive effect on riboflavin, pantothenic acid, and vitamin B in presscake, but did markedly reduce the availability of folic acid (Duckworth, 1955).

It was also reported by Wilmer (1957) from pilchards, that meals dried in coal- or oil-fired dryers consistently had a higher nutritive value than those dried in steam-tube dryers. He furthermore found that it is preferable to dry presscakes for a short time at high temperature than for a longer time at a lower temperature.

More recent studies under carefully controlled conditions show that meals of equal nutritive value may be produced by either the vacuum or the flame methods of drying provided care is taken that the meals are not overheated (Clandinin, 1949; Grau and Williams, 1955). In meals scorched during the drying process, the availability of the amino acids to the animal is reduced. The liberation of lysine, arginine, and possibly threonine was found by Clandinin (1949) to be affected by overheating even when tested by *in vitro* acid hydrolysis, and the liberation of all the essential amino acids was greatly depressed. Clandinin further reported and concluded, on the basis of feeding experiments with chicks involving diets in which fish meals were used to supplement cereal protein, that "overheating fish meal during drying depressed availability of the amino acids to such an extent that the damage done is irreparable by simple supplementation with the essential amino acids which acid hydrolysis values suggest as limiting." A combination of lysine, arginine, threonine, glycine, and methionine improved growth over that obtained with lysine alone, but growth rate was still not comparable to that obtained with fish meal which had been dried at a lower temperature. It seems probable, however, that although amino acids may be rendered unavailable when fish meals are subjected to heat treatment that a rather severe heating is required to render the fish meal protein resistant to the action of digestive enzymes. Under normal conditions, the temperatures used in good manufacturing procedure are not sufficiently high nor is heating sufficiently prolonged to result in protein damage. Comparative microbiological assays (Bissett and Tarr, 1954) of chemical and enzymic hydrolyzates of herring meal show that the availability of the essential amino acids was not altered by flame-drying as performed in normal commercial procedure nor by heating meal under experimental conditions for 1 hr. at 159°C. It was noted, however, that when heating was continued for 3 hr. at this temperature, the availability of all the essential amino acids was impaired. Carpenter *et al.* (1954) found no differences in the protein quality of whitefish meals produced by different drying methods.

More riboflavin was destroyed in the flame-drying than in other processes, but the protein quality and vitamin B_{12} were as high as with the lower temperature methods. The slightly darker color of the flame-dried meals was not necessarily an indication of poorer quality in these experiments. Laksesvela (1958), however, found that the extent to which meals were discolored by spontaneous heating after manufacture indicated the extent to which the nutritive value of the meals had been affected. High drying temperatures did appreciably reduce the vitamin B_{12} level of Spanish fish meals (Latorre Glanser, 1956).

Miller (1955) considers that the impairment in protein quality of commercial fish meals during drying is due to the action of heat in the presence of moisture and is the result of the Maillard reaction. Miller reported that commercial fish meals from various sources had protein utilization values (body weight × digestibility) of 60 as compared with 80 for fresh fish. The effect of overheating on the protein quality of fish meals is different from that with protein supplements of high carbohydrate content. With protein meals which contain little or no free carbohydrate, overheating results in lysine, and possibly arginine and histidine, forming new linkages to other amino acids which are resistant to enzyme action according to Almquist (1951). Lysine is one of the amino acids most apt to be rendered unavailable in fish meals that have been overheated. Since lysine is the primary limiting amino acid when cereals are fed as the only source of protein, any supplementary protein must first of all compensate for the lysine deficiency. British investigators have accordingly studied methods to assay fish meal quality on the basis of the available lysine content (Anonymous, 1957). One method involves the binding of the meal with an acidic dyestuff, orange G. Another method employs the reaction of the NH_2-group of "available lysine" with fluorodinitrobenzene. Carpenter *et al.* (1957) found that the protein value of commercial fish meals and of heated dried cod fillets for chickens could be increased by addition of lysine. Commercial fish meals gave results about 10% lower than those obtained with preparations which had been dried at a low temperature. Grau and Williams (1955) compared the nutritive value of a sample of tuna meal dried by a modified flame drier with the presscake used to make this meal. The presscake, preserved under isopropanol, was later dried in the laboratory in an air current at room temperature. The difference in growth rate observed was not significant.

Because many of the vitamins are heat-labile, overheating may seriously reduce the nutritive value of the fish meal through destruction of the vitamin content. Riboflavin was the first vitamin to be investigated in this connection and flame-drying was found to lower the amount of this vitamin present in meals so dried (Harrison *et al.*, 1935; Record *et al.*, 1934; Carpenter *et al.*, 1954). With different types of dryers involving different temperatures, the vitamin content of herring presscake was shown to drop from 3.9 to 19.1% in the case of riboflavin, 3.0 to 35.1% in the case of vitamin B_{12}, and 1.6 to 43.5% in the case of pantothenic acid (Klungsøyr *et al.*, 1953). Studying vitamin B_{12} only, Tarr (1952) found that heating to 159°C. of a specially prepared low-temperature-dried herring meal containing 0.204 mg. of vitamin B_{12} per pound reduced the vitamin B_{12} content to 0.115, 0.056, and 0.035 mg. per pound depending upon whether heating was for 1, 2, or 3 hr. Carpenter *et al.* (1954) compared the vitamin B_{12} content of meals produced by different commercial drying procedures and found the vitamin B_{12} content of flame-dried meals to be as high as in meals produced by lower-temperature methods. Southcott and Tarr (1953) on the basis of the microbiological assay method do not consider there to be a significant difference in the vitamin B_{12} content of experimentally produced low-temperature air-flow-dried meals and commercial herring meals.

The folic acid activity in different foods is lost upon cooking. Cheldelin *et al.* (1943) reported that cooking halibut or salmon flesh destroyed or rendered unavailable as much as 74% of the folic acid content. Lillie and Briggs (1947) on the basis of chick assay found no folic acid activity in menhaden meal. Biely *et al.* (1952) showed that commercial flame-dried herring meals are likewise poor sources of folic acid. The effect of processing temperature on the folic acid content of herring meal was investigated by comparing low-temperature laboratory-dried meal and commercial flame-dried meal prepared from the same lot of herring presscake. From data obtained in both microbiological and chick assays, it was apparent that the high temperatures encountered in the flame-drying process in the commercial manufacture of herring meal are responsible for the low folic acid content of these meals. There have been no comparative studies made of commercial meals prepared by different processes for folic acid content.

Karrick and Stansby (1954) obtained samples of presscake and of meal prepared from the presscake from different plants. The different plants employed a direct flame-dryer, an indirect flame-dryer (approximately 250°F.) and an airlift dryer (approximately 170°F.). Analysis was made of the presscake and the meals for riboflavin, nicotinic acid, and vitamin B_{12}. There was no significant loss of vitamins upon drying the presscake except in the case of the nicotinic acid when the meal was dried in the direct-flame dryer. The vitamin B_{12} content of presscake was unaffected when the presscake was dried at 80 to 100°C. for 5 hr. Bird (1959a) reported that the unidentified growth-factor potency in menhaden meal was not reduced by overheating during processing with either 3-hr. cooking period or a 3-hr. drying period at 390°F.

Biely *et al.* (1951) reported that the adverse effect of overheating on the nutritive value of herring meal was in part due to changes induced in the oil. When a laboratory preparation of herring meal dried at low temperature was heated for 3 hr. at 159°C., its nutritive value was impaired. If, on the other hand, the meal had been extracted with diethyl ether prior to heating, the heating had no deleterious effect. When the oil present in the heated, unextracted meal was extracted and added to the extracted, heated meal, the nutritive value of the latter was markedly impaired. Similar addition of fresh herring oil had no undesirable effect.

With reference to the effect of drying temperature on the nutritive value of fish meal, some interesting results were obtained with Japanese sun-dried herring meal in 1935 at the University of British Columbia. The herring were prepared by splitting and stringing on wires to dry in the sun. A considerable amount of the oil dripped out, but the free fatty acid content of the residual oil was extremely high. When the product was fed in the chick starting rations used at that time, it gave comparable results to dried milk products (Biely, 1935).

C. STORAGE

The findings with respect to the effect of storage on the quality of feeds in general are conflicting, with many reports stating that no detectable deterioration is to be found resulting from storage. Evans *et al.* (1944b) reported that there was no loss in the supplementary protein value of pilchard meals after storage for 10 months in paper, cotton, or burlap bags. Biely *et al.* (1951) found that nutritive value of herring meals stored for one year at —25°, 21°, and 37°C. was unaffected when the basal diet in which the meals were tested was well fortified with vitamins. These results showed that the value of the meals as protein supplements was unchanged. Storage at room temperature for 3 months did not affect the protein nutritive value of dry cod proteins according to Miller (1955). Almquist (1956), on the other hand, on the basis of *in vitro* tests found the digestibility of protein by pepsin to be decreased upon storage. Samples sealed in glass tubes, however, showed little alteration in composition. Lea *et al.* (1958) showed that herring meals stored in air showed rapid oxidation of the oil content. The meals had been prepared by hot-air drying of the presscake with moisture contents of 11.1 and 6.2%. Oxidation was more extensive at the lower moisture content. It also was found that after 12 months' storage there was a decrease in available lysine of 9%, but that no decrease in available lysine occurred in whole meals stored in nitrogen or in defatted meals stored in air. These changes may be compared with those reported to occur in the digestibility of soybean oil meals as a result of storage. Jones and Gersdorff (1938) demonstrated that the enzyme digestibility of the protein in soybean oil meal decreased during storage and that the change varied depending on the amount of fat in the sample and the nature of the storage container. Tappel (1955) studied the interaction of protein with oxidizing fat. Insoluble dark-brown copolymers of high oxygen and nitrogen content were formed from which the total amino acids recoverable, even after acid hydrolysis, was about 16% lower than would be expected from their nitrogen content, indicating an appreciable destruction of amino acids.

The large surface area provided by fish meal permits ready oxidation of the oil content of the product. Stansby and Clegg (1955) and Almquist (1956) observed that the extractability of fat from stored fish meals decreased progressively with storage. In the first few hours after processing, considerable heating occurs. The probability that oxidative processes involving the fat content of the meal are inducive to this heating was suggested by Harrison (1939b), who noted that heating in low-fat meals was not so extensive as in high-fat meals. Contrary to this, Dreosti and Rowan (1958) established that ordinary fish meals are more subject to heating than are whole meals. Obviously other factors than the straight oxidation of oil are involved in the spontaneous heating of fish meal. Another unexplained observation was made by these investigators. The reactivity of a fresh meal mixed with a well-cured meal is reduced to a greater extent than one would expect on the basis of simple arithmetical mixture relationships.

Gehrt *et al.* (1955) found that, although the percentage of pepsin-indigestible matter was low in fish meal that had been properly processed, several samples that had overheated spontaneously during rail transit contained extremely high percentages of indigestible material. Grau and Williams (1955), in view of the possibility of heat damage occurring in meals which had undergone oxidative heating or "curing," tested different samples of tuna meal. Two samples were collected for each of three tuna meals. One sample was taken from part of a pile of meal which had been "adequately ventilated," and the other was taken from a region in which the heat generated during heating had been retained within the meal by the insulating action of several inches of meal. Of the three meals tested, only one was of good quality. However, in neither the good-quality meal nor in the inferior meals was there a difference in the rate of growth promoted by the sample from which the heat was dissipated and that which was allowed to heat. This finding is contrary to that of Meade (1956), who stated that meal produced by scrap-pile curing is not so good a source of amino acids as that produced when the heat is dissipated or in which oxidation is controlled. If it were possible to prevent the initial heating or to allow it to proceed under controlled conditions, it would be possible to store and to handle meal in bulk at a saving to the feed manufacturer (Kyte, 1957).

While the development of rancidity in the oil content of fish meals doubtless results in destruction of some of the vitamins, there has been little experimental work on the effects of the oil content of stored fish meal on the growth rate of animals to which the meals may be fed. There is considerable evidence as to the toxicity of oxidized-polymerized oils. Gray and Robinson (1941) concluded that a high free fatty acid content in animal protein concentrates is not a true factor for the evaluation of the nutritive worth of these products when used in well-balanced rations for poultry feeding and that high rancidity of the fat in animal protein concentrates does not necessarily affect the nutritive value of such products when they are used at a 10 to 15% level in poultry feeds.

Laksesvela (1958) investigating the effects of spontaneous heating in fish meal found that, although lysine and methionine are damaged in heated meal, histidine appears to be rendered unavailable to a greater extent than either of these amino acids. From the practical standpoint, the damage to lysine and methionine is probably of greater concern because both are necessary to compensate for deficiencies in the cereals which constitute the major portion of livestock feeds. Laksesvela raises the interesting question of whether spontaneous heating after manufacture results in the same type of damage as excessive exposure to heat in a drier during manufacture and points out that, whereas spontaneous heating may occur over a considerable period of time, meal in a drier reaches a higher temperature but for a relatively short time. Tests of meals which had undergone spontaneous heating of varying intensity showed that digestibility on the basis of pepsin-HCl digestion had fallen by 50% for the most severe heating but by no more than 4 to 8% for moderate heating. The results of the chick feeding tests indicated much greater damage than would be expected from the digestibility figures.

The above reports have referred to the effects of normal storage on fish meals. There are, in addition, a few references to the effects of adverse storage conditions on the nutritive value of fish meals. Lanham and Nilson (1942, 1947) found that experimental spoilage of sardine meal with heat and moisture in which both chemical decomposition and chemical hydrolysis took place did not adversely affect the nutritive value of the protein. Subsequent studies (1947) in which feeding tests were conducted on commercial meals prepared from pilchard, menhaden, and fish fillet scrap showed that experimental spoilage of these meals under conditions of high heat and humidity and under aerobic conditions did not produce any toxic compounds. While conditions that would result in mold growth in fish meal are obviously extreme, it is interesting to note an instance in which Grau and Williams (1955) compared a moldy meal with a nonmoldy one and found that both meals were equally good sources of amino acids for chicks.

The effect of conditions and duration of storage on the vitamin content of fish meal does not seem to have been studied to any extent. In most reports on the vitamin level of meals no mention is made of the age of the meals which have been assayed. Bird (1959a) found that the unidentified factor in fish meal is quite stable. Storage in air for 18 months at room temperature did not reduce the growth-factor potency in menhaden meal as measured by the method of Barnett and Bird (1956).

D. Antioxidants

Antioxidants are widely used in the fats and oils industry and they may find application in the manufacture of fish meal. The use of antioxidants in the latter connection is as yet in the experimental stage. The addition of diphenyl-*p*-phenylenediamine (DPPD) to fish meal has been reported to control oxidative processes during the curing of menhaden meal (Meade, 1956). The use of this antioxidant is now prohibited. Studies employing Santoquin,* DPPD, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), propyl gallate (PG), and nordihydroguaiaretic acid (NDGA) in tuna meal have been reported by Brown *et al.* (1957), who found that the slowing of the oxidation rate by any one antioxidant was closely related to the method by which it was added to the meal.

Lea *et al.* (1958) measured the effect on the rate of oxidation of the oil content in herring meal of BHT at a concentration of 0.005% in combination with 0.005% citric acid and found that oxidation was considerably retarded. In connection with the possible use of antioxidants to stabilize the fat content of fish meal, these investigators suggest that "in view of the known adverse effects of highly unsaturated fish oils in the diet, the advantage of retarding oxidation of the oil in the fish meal is perhaps doubtful."

Menhaden meal to which BHT was added could be bagged or placed in bulk storage immediately (Anonymous, 1957). Spontaneous combustion hazard was thus overcome, as excessive heating of the meal was eliminated.

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* 6-Ethoxy-1,2-dihydro-2,2,4-trimethylquinoline.

Experiments to determine if antioxidant treatment might be employed in bulk handling of fish meal showed that 0.01% of Santoquin added to the dried scrap did not eliminate heating, although the maximum temperature reached by the meal so treated was reduced (Kyte, 1957).

IV. Condensed Fish Solubles

The composition of fish solubles varies considerably, depending on several factors. Differences in composition can be expected due to fish species. Solubles may be made by reduction of fish scraps arising from filleting or canning operations and hence do not represent extractives from the whole fish. Within a species, marked variations exist in body composition, depending on the stage of maturation and seasonal and sexual state. Finally, the composition is associated with the management of the reduction plant. The freshness of the fish raw material, the type of machinery employed in the manufacture, and the extent of bacterial decomposition of the stickwater are some essential factors influencing the final composition.

Special mention should be made of the complete dehydration of fish solubles as a relatively recent development on a commercial scale. Several literature reports have already indicated that such drying of solubles on carriers, e.g., soybean oil meal, retains the unidentified growth- and hatchability-promoting effects of the original solubles (Johnson and Waibel, 1960).

A. VITAMIN CONTENT

The press-water or stickwater from the wet reduction of fish was for many years regarded as a liability and constituted a serious disposal problem. In 1931, Harrison discussed the considerable losses of material that occur in the wet reduction of menhaden. Likewise, in 1933 Beale reported on the losses of oil and protein in the effluent of pichard reduction plants in British Columbia. As awareness grew of the vital role of the vitamins in nutrition and as the list of water-soluble vitamins became longer, possible sources of the vitamins were investigated. Because of the nature of the wet-reduction process, it was logical to suspect that a considerable proportion of the water-soluble vitamin content of the fish was being lost in the stickwater rather than remaining in the press-cake. In fact, most of the early studies on the nutritional value of fish meal favored the meals prepared by the dry-rendering process over wet-rendered meal. In view of the vitamin-deficient diets commonly employed at that time, this conclusion was probably due to the fact that the water-soluble vitamins were retained in the dry-rendered meal.

Lassen (1940), having found press-water to be a rich source of riboflavin, developed a process for concentrating the vitamins from fish press-water with the object of producing a concentrate rich in riboflavin and other factors which would be a suitable supplement to human foods, as well as to poultry and livestock feeds. Synthetic riboflavin was, however, soon to be available at a price which made its use by the feed industry almost universal. The other B-complex vitamins were likewise being offered in feed supplements of guaranteed potency, usually as the by-products of one of the fermentation industries. During the war years, there developed a considerable production of condensed fish solubles. The product was considered as a substitute for milk products, and its use was particularly popular in those areas in the United States where corn and soybean oil meal are the principal components of poultry feeds.

After pure riboflavin began to be produced commercially, fish solubles continued to be used again particularly in the midwestern United States for what came to be widely referred to as the animal protein factor or APF. Following the discovery of vitamin B_{12}, the animal protein factor was identified with this latest vitamin of the B complex. As in the case of riboflavin, it was not long before it was possible to produce vitamin B_{12} in high concentration as a fermentation product. The use of condensed fish solubles continued despite the availability of riboflavin and vitamin B_{12} from other sources. Apart from the possible presence of unidentified factors which will be discussed under a separate heading, fish solubles is a valuable natural source of the vitamin B complex.

Berry *et al.* (1945) found that 2% condensed fish press-water or 2% fish liver meal (a product containing 50% soybean oil meal) seemed to supply all factors except riboflavin, vitamin D, and minerals needed to supplement rations composed of ground yellow corn as a source of energy and soybean oil meal as a protein supplement. Three per cent of sardine meal was inferior to 2% of condensed fish press-water or 2% fish liver meal. An anonymous Norwegian report (1952) states that 40 to 60% of the total amount of vitamin B_{12}, niacin, and pantothenic acid in fresh frozen herring goes into the press-water in the reduction process. Nehring (1956) established that 60% of the B_{12} originally present in the whole fish is contained in the fish solubles. From these and other reports it can be seen that condensed fish solubles, even disregarding the possibility of unidentified factors, is a valuable adjunct to poultry rations.

Turkeys have very critical vitamin requirements, and the cost of supplying vitamin supplements in their rations is considerable. Experiments conducted by March *et al.* (1959) showed that condensed herring solubles is an effective supplement. With the practical type of diets employed in the tests, poults showed a greater growth response to condensed herring solubles than to dried brewers' yeast. The difference between the response to condensed herring solubles and to dried brewers' yeast occurred with rations containing herring meal and also with rations containing no herring meal but fortified with vitamin B_{12}. In connection with the use of condensed fish solubles in turkey rations, it may be noted that Odland *et al.* (1955) report that turkeys fed 3% condensed fish solubles showed no off-flavors attributable to the solubles even after frozen storage.

B. Unidentified Factors

In addition to being a rich source of many of the B-complex vitamins, condensed fish solubles may contain one or more unidentified factors necessary for the maximum growth rate of chicks and poults and possibly for the hatchability of eggs. Not long after the discovery that vitamin B_{12} was an essential nutrient for poultry, it became apparent that vitamin B_{12} activity did not account for all of the growth stimulus when fish meal or condensed fish solubles was added to all-vegetable rations.

Hill (1948) reported that fish meal and condensed fish solubles were carriers of an unidentified factor. Carlson *et al.* (1949), using a purified diet, found that 3% fish meal and 7.5% dried brewers' yeast greatly improved growth to 4 weeks in chicks and prevented the mortality which occurred with the basal diet. Sunde *et al.* (1950) found evidence that chicks fed practical rations required an unidentified factor in addition to vitamin B_{12} and other known vitamins for maximum growth. Whole liver powder and crude condensed fish solubles were sources. Combs and Shaffner (1950) reported that dried brewers' yeast, fish meal, and crab meal supplied unidentified factors stimulating growth in turkey poults. Poults in experiments conducted by Richardson and Blaylock (1950) showed a variable response to the addition of fish meal or condensed fish solubles to a milo-soybean oil meal ration. Heuser and Norris (1951) concluded that fish meal, condensed fish solubles, and homogenized fish contained some as yet unidentified factor. A condition in growing turkeys known as "hock disorder" was reported by Combs (1951) to be reduced in incidence by fish meal, dried brewers' yeast, crude liver preparations, and butyl molasses solubles. These products stimulated growth as well. McGinnis *et al.* (1952) also obtained a growth response to condensed fish solubles with poults and chicks. Patrick (1951) reported that poults fed high soybean oil meal rations responded to supplements of fish meal, fish solubles, and the methanol fraction of fish solubles. Fuller *et al.* (1952) obtained an added growth response in chicks fed fish solubles, dried whey, or Wilson's liver fraction "L" in addition to vitamin B_{12}. These findings suggest the presence of unidentified factors required by the chick in these products. Laksesvela (1954) obtained significant growth promotion with herring meal, full meal, and condensed solubles. There was no difference in the effect of full meal and solubles. Unidentified growth-factor activity was found to be present in a wide variety of fishery by-products according to a recent investigation by Sullivan *et al.* (1960).

Many claims have been raised as to the presence of unidentified growth factors without sufficient evidence. It is gratifying that efforts now are being made to design methods for a reliable bioassay of such growth factors (Ershoff and Geiger, 1957). Several investigators have studied the interrelationships between these unidentified growth factors and antibiotics (see further Menge and Lillie, 1960). The growth-promoting effect of antibiotics needs to be distinguished from that of constituents in solubles. Barnett and Bird (1956) stated that the response to fish solubles may be dependent upon the presence of particular intestinal microorganisms, since high-level CTC inhibited the growth response to fish solubles. Combs *et al.* (1954) suggested that their failure to obtain a growth response from fish products was due to the presence of penicillin in the basal ration. On the other hand, arsanilic acid is dependent for its growth response upon the presence of fish meal or other fish solubles in the ration. The fish factor is apparently quite stable to ordinary conditions employed in the processing and storage of fish meals (Sullivan *et al.*, 1960). Some evidence has been presented that the responsible factors in the fish solubles possibly might be unidentified micronutrients (Wisman, 1960).

Comprehensive reviews covering the entire field of unidentified factors and their presence in fishery products, chiefly solubles, were published in 1953 by Branion and Hill, in 1954 by Sanford and in 1959 by Bird.

The question of whether there may also be unidentified factors required for maximum hatchability as well as for maximum rate of growth has also been investigated. Stephenson and Clower (1952) kept breeding hens on an all-vegetable diet and on the same diet with the addition of 13% condensed fish solubles. The hens were kept on built-up litter. Within 4 weeks the hatchability of fertile eggs from the all-vegetable diet had dropped 15%, but there was no change in the hatchability of eggs from the hens fed the condensed fish solubles.

Progeny studies also indicated a decreased hatching weight and retarded growth in the chicks produced by the hens on the all-vegetable diet. Arscott and Combs (1953) found that fish solubles gave a more pronounced improvement in the hatchability of eggs from birds housed on wire floors as compared with those on litter. There was also evidence of a carryover to the chick of the unidentified factor supplied by condensed fish solubles. Ferguson *et al.* (1956) fed turkey hens on all-vegetable basal ration (fortified with vitamin B_{12}) and supplemented it with various combinations of dehydrated alfalfa meal, condensed fish solubles, and vitamin E for a period of 20 weeks. From 1 to 8 weeks there was little difference in hatchability from the differently supplemented diets. From 9 to 20 weeks there was a drop in hatchability with all diets except that supplemented with the combination of dehydrated alfalfa meal, fish meal, and vitamin E. Feldman *et al.* (1957) showed that supplementation of an all-vegetable turkey breeder diet with alfalfa meal, dried brewer's yeast, and condensed fish solubles increased hatchability in the presence of adequate vitamin E. The data suggest the possibility that condensed fish solubles contains an unidentified factor which reduces embryonic mortality during the last week of incubation. Kurnick *et al.* (1956) fed breeder hens a purified diet and found that the diet resulted in poor hatchability resulting from a high incidence of embryonic mortality during the first week of incubation. The unidentified factor, the deficiency of which was responsible, was found in liver preparations, fermentation products, and condensed fish solubles. Supplementation of the basal diet with fish solubles increased hatchability from 28 to 84%.

In addition to the above reports indicating the presence of an unidentified factor promoting hatchability, there have also been instances reported where no effect on hatchability could be demonstrated. Couch *et al.* (1950), for example, were unable to demonstrate any improvement in hatchability when fish solubles were fed to breeding hens, although they did find evidence for an unidentified factor for hatchability in liver fraction "L." Similarly, Cooper *et al.* (1961) found no difference in hatchability of turkey eggs from hens fed diets with and without herring solubles. Whether or not the differences noted in the response to the inclusion of condensed fish solubles in the diet with regard to hatchability are due to some management factor influencing the amount of the factor available to the hens through coprophagy or to strain or breed differences in the requirement of birds for the factors has yet to be elucidated.

Attempts have been made to fractionate fish solubles in order to concentrate the factor. Menge *et al.* (1953) showed that the factor was soluble in water, phenol, 50, 60, and 80% ethanol, and 70% methanol but insoluble in ether. It was also found to be dialyzable and stable to autoclaving at pH 2.0 to 11.0. According to Taminie (1955), the growth stimulus resulting from the addition of fish meal to a purified diet is due to at least two unknown factors. One factor is extractable from the meal with water and is acetone-soluble, and the second factor is present in the ash. Taminie considers the fish factor to be identical with liver factor but distinct from the whey factor, the alfalfa factor, and the factor present in distillers' dried solubles. Ritchey *et al.* (1956) found that intact fish meal always increased growth significantly but that the response obtained to the ash from fish meal was variable.

Assay methods for the unidentified factors have been described by Lillie *et al.* (1953) and by Barnett and Bird (1956). The latter investigators observed that the response to a growth factor in fish solubles apparently depends upon the stock used and upon the presence of a particular microorganism or group of microorganisms in the environment.

There is little agreement between laboratories as to the nature of these growth-stimulating substances or to the extent of animal responses. The variations in results may be ascribed in part to differences in the types of basal rations and the history of the livestock animals being tested. More important still is the composition of the tested fish solubles. Only rarely is the source or history of the fish solubles revealed, or considered in the interpretation of the results obtained. Definite conclusions regarding these unknown growth factors will have to await studies with carefully standardized samples.

C. Protein Quality

The protein quality of condensed fish solubles depends on the condition of the raw fish and on the processing procedure. Almquist (1949) states that if fish solubles merely are the condensed or dried stickwaters, the protein quality is at a minimum, while if varying amounts of solids or fines are left in, the product will have a somewhat higher protein value. This essential feature is further elucidated in Chapter 22 of Volume III.

Lassen *et al.* (1949b) studied the relation of the nutritive value for chicks of condensed fish solubles to the quality of the raw material and found that the material with the greatest amount of spoilage allowed the poorest chick growth. From the several factors studied, the one which seemed to have the greatest influence upon the nutritive value of condensed fish solubles was the degree of freshness of the raw material. There was a general decrease in amino acids with spoilage, and individual amino acids were destroyed at different rates. The authors believe that this was probably due to air-borne microorganisms. The shift in nitrogen distribution from true protein to nonprotein nitrogen and ammonia as a measure of the nutritive value and spoilage was correlated with chick growth. Evans (1954) studied the nutritive value of condensed fish solubles in pig feeding. When fish solubles was fed to supply an amount of protein equivalent to the feeding of 7% of whitefish meal, the nutritive value of the crude protein of the fish solubles was inferior to that of the whitefish meal. This was shown in both growth and nitrogen-balance tests. It was concluded, however, that the fish solubles were useful as a protein supplement for cereal grains.

D. Stimulation of Rumen Microflora

There is evidence that fishery products may have special beneficial effects in the feeding of ruminants. MacLeod and Brumwell (1954), using the artificial rumen technique, found that cellulose digestion is considerably stimulated by the inclusion in the fermentation medium of condensed whale solubles, condensed herring solubles, herring stickwater, or a hydrolyzate from halibut muscle. *In vivo* studies with sheep carried out by Chalmers and Synge (1954) showed that herring meal was a more effective protein supplement than casein in promoting nitrogen-retention and growth and that herring meal resulted in less ammonia formation in the rumen.

V. Other Products

A. Whale Meal

On the basis of the evidence in the literature, whaling by-products vary considerably in their value as supplements for animal feeding. There are numerous reports in which the feeding value of whale meals is compared with that of other sources of supplementary protein. Care has to be exercised, however, in assessing these accounts because of the variation in the other products being used for comparison. This is particularly true of reports originating in countries where livestock and poultry feeding is not the highly competitive and technical industry that it is in Canada and the United States.

Golding and Morris (1926) reported that whale meal was a satisfactory supplement for feeding pigs. They reported that there was no tainting of the carcasses and that there did not appear to be any softening of the fat when unextracted meals were used or when the rations were supplemented with whale oil. Wilgus *et al.* (1933a, b) compared the protein value of whale meal to that of different types of fish meal in a chick feeding test and found that whale meal gave the poorest results of the products tested. Almquist *et al.* (1935), on the other hand, compared whale meal to sardine meal and found both to give satisfactory results as supplementary sources of protein in chick rations. Halnan (1942) reported that whale meal was a supplement of high biological value for chicks. He also noted that low-temperature-dried meal gave better results than meal dried at a high temperature. Biely (unpublished data) noted that whale meal was a much more variable product that the fish meal produced on the British Columbia coast, although some of the samples tested were of good nutritive quality as protein supplements in chick rations. Yagovkin (1952) compared whale meal to sunflower meal and found the two supplements to be about equal in nutritive value.

Carpenter *et al.* (1955) made a detailed study of the vitamin and amino acid composition as well as the protein biological value for chicks of a number of samples of whale meal. The details of the processing were known for the several meals. The results indicate that, provided drying is carried out under controlled conditions, it does not have a deleterious effect on protein quality and that meals produced by this process are comparable in quality to vacuum-dried meals. The data on the meals also indicate that any decomposition occurring during the normal range of time between capture and reduction does not impair the quality of the meal.

Von Steinegger and Zanetti (1957) showed that, with carefully produced whale meat meal, broilers showed the same rate of growth as with codfish meal. Chicks fed normal whale meat meal and whale meals boiled under pressure and with higher percentages of bones showed similar rates of growth but less than with the pure whale meat meal and codfish meal. Normal whale meat meal which had been carefully produced gave better results than ordinary meat meal and was similar in value to good codfish meal. Studies conducted by Australian investigators (Hope *et al.*, 1954; Hewitt, 1957) showed meat meal and whale meal to be about equal in nutritive value for pigs when fed at levels of 10%.

Several investigators have established the good nutritive quality of whale meat meal as long as first-grade flesh is utilized. The essential amino acid content does compare well with that of fish flesh and is equivalent to that of other animal proteins (Lyman *et al.*, 1956; Carpenter *et al.*, 1955; Pritchard and Smith, 1960). Meal produced in land stations contains more B_{12} than that from floating factories, according to Pritchard and Smith (1960).

B. Condensed Whale Solubles

Condensed whale solubles is a by-product of the whale-reduction industry corresponding to condensed fish solubles. Condensed whale solubles, however, is not so good a source of B-complex vitamins as most samples of condensed fish solubles according to data of Lassen *et al.* (1951) and Tarr *et al.* (1952). Hewitt (1954) found that whale solubles did not promote as fast a rate of growth nor have as good feed efficiency in pigs as did meat meal when the two products were fed as supplements to a grain and alfalfa ration.

The results of vitamin analysis are confirmed by the relative response to condensed whale solubles and condensed fish solubles in feeding tests. Biely *et al.* (1954) showed that when the two types of condensed solubles were fed in all-vegetable chick starting rations at 2.5% of the ration, the stimulus to growth was better with the herring solubles. Milne (1955) reported the results of an experiment in which condensed whale solubles was used to replace all or part of the meat meal in a chick starting ration. Growth was progressively depressed by increasing amounts of solubles in the ration, with high mortality, dermatitis, and poor feathering in some instances. The protein of condensed whale solubles is low in tryptophan and cystine, although the total protein content of whale solubles is higher than in condensed sardine solubles. Lassen *et al.* (1951) found that, when whale solubles is supplemented with tryptophan and cystine, it could replace soybean up to a level of 20% in the ration. No off-flavors were noted in 8-week-old birds which had been fed this level in the ration.

C. Dogfish Meal

In spite of large catches of dogfish for the liver oil, there has never been any appreciable production of meal. The livers are generally removed and the remainder of the carcasses discarded. Processing of the carcasses is difficult because of the toughness of the skin and the high collagen content in the fish.

During World War II, there was a flurry of interest in dogfish meal as an animal feed, and some nutritional studies were made. The nitrogen content does not give a valid estimate of the protein content in the case of dogfish meal because of high levels of nonprotein nitrogen in the form of urea and trimethylamine oxide. Urea nitrogen is not utilized by chicks, and consequently the nitrogen content of dogfish meal has to be discounted if the meal is intended for poultry feeding. In 1953, Almquist *et al.* had reported that dogfish meals gave inferior results compared with other animal protein concentrates in chick rations. (See also Ackerson *et al.*, 1940; Heller and Penquite, 1941).

Processing methods are of critical importance when elasmobranchs (shark, dogfish) are converted into meal. Dogfish meals made by dry-rendering processes may have little or no value as supplementary proteins, but meals made by wet-rendering were about equal in value to fish meal for chicks and pigs (Rhian *et al.*, 1942; Evans *et al.*, 1944a; Duckworth, 1955).

Grau (1947) obtained poor results with dogfish meal in feeding tests with chicks even when the protein level in the meal was corrected for the urea present.

Marshall and Davies (1946a, b) studied the nutritive value of shark meal (shark not specified) prepared by a wet process and found that the nonprotein nitrogen present did not appear to interfere with the efficiency of the rations. These workers also fed shark meal to pigs (1946b) and concluded that, on the basis of the crude protein content, shark meal is an acceptable source of protein for use in swine rations. No fishy flavor was detected in the meat or fat of the animals when the ration contained up to 13% of shark meal.

D. Shellfish and Starfish Meal

There is some production of crustacean meal from the waste material remaining after the edible meats are taken from crab, lobster, and shrimp. The mineral content of such meal is higher than that of fish meal.

The normal Kjeldahl procedure for the determination of crude protein gives erroneously high values for shellfish meals unless correction is made for the apparent protein contributed by chitin, an N-acetylated glucosamine polysaccharide. Methods for determining chitin nitrogen have been devised by Black and Schwarz (1950) and by Brown (1959). Parkhurst *et al.* (1942) investigated the nutritive properties of crab meal and reported that the crude protein content was 72% available for the chicken. A report (Anonymous, 1953-57) on the value of lobster meal as a source of protein for growing chickens states that the response obtained was similar to that with soybean oil meal but inferior to that with fish meal.

In the Union of South Africa, the greater part of the waste from crayfish tailing and canning plants is used to produce meal. In the United States some waste from shrimp-processing operations is converted into meal for poultry. Also, in Australia crayfish and prawn offal is now being made into feed (Anonymous, 1957c).

The moisture content of this waste is reduced to 55% or lower prior to drying in order to overcome the tendency to stick, particularly in rotary driers. Australian crayfish waste had an average protein content of slightly less than two-thirds that of ordinary fish meal.

Some crustaceans contain relatively large amounts of riboflavin, and some of the tissues from certain crabs are among the richest known sources (Busnel, 1942, 1943). An experiment reported in 1934 by Record *et al.* in which the riboflavin content of the meal, rather than the quality of the protein, was measured showed crab meal to be a good source of riboflavin and superior in this respect to several samples of fish meal. Good results were obtained also with one sample of shrimp meal.

Starfish meal can be used as a protein supplement in poultry rations (Stuart and Hart, 1944). When fed at low levels to chicks, it is only slightly less effective than good quality fish meal (Whitson and Titus, 1946; Lee, 1948). As with shellfish meals, the mineral content is high and limits the amount of the product which may be incorporated into a ration. Due to this, the following method has been developed by the Japanese for making starfish solubles. The raw starfish is submitted to enzymic digestion. The body wall of the starfish is digested, and pieces of calcium carbonate emerge. These are removed by filtering. The filtrate thus contains a lesser amount of calcium, making it more suitable for animal feeding. Starfish solubles, besides being a source of amino acids, are said to be rich in several vitamins. In place of commercial enzymes, the liver of blue crab can be used for the starfish digestion. The water content of the filtrate is generally reduced below 50% (Higashi *et al.*, 1955).

Protein concentrates prepared from starfish either by pancreatic digestion or by washing with hydrochloric acid were found to have high protein quality values, comparable to good-quality fish meals (Levin *et al.*, 1960). In this same study it was shown that defatted starfish meal approximately equals fish meal, on a protein basis, when added at levels of 3 to 6% to practical diets, while maintaining the same dietary calcium level.

E. FISH SILAGE

Fish silage was originally introduced as a means of utilizing waste fish in locations where the volume was not sufficient to warrant the installation of equipment for any elaborate processing of meal. Most of the studies regarding the nutritive quality of fish silage have been conducted by Scandinavian, German, and British investigators (Kreuzer, 1952-53; Petersen, 1951; Olsson and Olofsson, 1955; Carpenter and Olley, 1958; Hansen, 1959). The preparation of fish ensilage has been confined largely to small operations, with the product being marketed in the vicinity of the plant. There has, however, been some interest in the development of a liquid product from whole fish which might be added to rations by the feed manufacturer in much the same way as condensed fish solubles.

As soon as raw fish products are involved, the menace of thiaminases becomes acute. This hazard is discussed in detail in Volume I, Chapter 13. Important is the fact that the Atlantic herring on the European side, in contrast to that along the American coast, appears to carry this detrimental antienzyme and consequently constitutes an obvious risk.

In principle there are two major methods for the preparation of fish silage. One is a controlled fermentation, sometimes enhanced by the addition of a carbohydrate source (grain, potato, etc.). The second procedure is based on the adding of preservatives, thus suppressing any major spoilage of the fish raw material. This latter method is also employed in the short-range storage of raw fish, later to be used in the manufacture of either oil or meal, possibly solubles. Acids are the chief preservatives employed.

The use of silage has been studied in connection with both poultry and hogs. One is advised against feeding silage to other than layers (Hansen, 1959). When acid silage is fed to hogs, it should be neutralized, so pH never exceeds 3.5 (Hansen, 1959). As with other fish products, it also should not be administered too close to the time of slaughtering (Pecht, 1954). Otherwise, it might impair the fat stability of the meat.

1. *Wet Silage*

The age-old method of microbial control through acids—thus adjusting the pH—has been adopted in the making of fish silage. Most acids tolerable to livestock have been employed, such as hydrochloric, sulfuric, acetic, formic, and lactic acid (Edin, 1940; Olsson, 1942)—for further information see review by Olsson and Olofsson (1955). By adding lime or chalk at the moment when livestock are being fed, any excessive acid may be neutralized. No detrimental effect of such acidification has been observed on either vitamin A nor vitamin D.

This acidification induces a gradual breakdown of the fish material, which finally is converted into a fairly homogeneous slurry. During the summer, with correspondingly higher temperatures, the consistency becomes more liquid.

The suitability and effectiveness of formic acid has been extensively studied (Olsson, 1942; Kirsch *et al.*, 1943; Petersen, 1951; Sperling, 1951, 1952; Pecht, 1954; Olsson and Olofsson, 1955). Formic acid, in contrast to mineral acids, has the advantage of being metabolized in the animal intestines.

Acid formation through natural fermentation, chiefly by relying on the formation of lactic acid, is the foundation for the preservation of a major part of the fish silage. This procedure has also been most successfully employed with fish. Common carbohydrate sources are potato (Kirsch *et al.*, 1943) and molasses (Kreuzer, 1953; Olsson and Olofsson, 1955; Bertullo, 1958). The application of molasses and inoculation with lactic acid bacteria are the basis of a patented Danish method, giving what is designated as LKC-feed (see Pecht, 1954). Sugar utilization for acid formation at 68°F. (20°C.) is unfavorable, 2.5 times more sugar being used as compared to what is required at 77°F. (25°C.). This latter temperature is closer to the optimum for lactic acid-producing organisms, being at 68 to 77°F. (25° to 30°C.) with *Lactobacillus plantarum* (Kreuzer, 1954).

Besides the above-mentioned acids, the following preservatives have proved efficient in fish silage: sodium nitrite, formaldehyde, antibiotics (Thomson *et al.*, 1956), quaternary ammonium compounds, bisdiguanide (Davies *et al.*, 1954), sodium metabisulfite, hypochlorite, sulfur dioxide.

Dipping as a method of application is superior to permanent immersion in a solution (Carpenter and Olley, 1958). A solution containing 1% formaldehyde plus 1% nitrite was found satisfactory for herring. The amount of preservative required for whitefish is 2–3 times that required for herring. It is advisable to blend preserved meal with untreated meal to reduce the residual nitrite content. A quaternary ammonium compound showed promise for very short-term storage, and a diguanide warrants further tests in view of its favorably low toxicity. In general, nitrite and formaldehyde have been found to be the most satisfactory preservatives in this new study by Carpenter and Olley (1958).

Hvidsten (1955) found that herring meal containing 200 mg. of sodium nitrite fed daily to a 30–90 kg. pig produced no measurable quantity of methemoglobin in the blood, while herring meal containing 1,000 mg. of nitrite fed daily gave a maximum of 2% methemoglobin in the blood. Basic toxicological studies have been conducted by Stormorken *et al.* (1955). Hence, herring meal containing 0.4% nitrite fed at a level of 8% in the diet produced no clinical symptoms. A herring meal with 0.03% nitrite should have a very great safety margin. The Norwegians have, however, limited the allowed amount to 200 p.p.m. because nitrite, although not toxic per se, caused symptoms of vitamin A deficiency when cod liver oil was mixed with the diet. Preservatives are not only employed in silage, but are employed for preserving the raw material prior to their use in the manufacture of fish meal or fish solubles

(Thomson *et al.*, 1956). Extensive practical tests have been made in Norway of feeding nitrite-preserved herring (200 p.p.m.) to cattle (Flatla, 1955), dairy cows (Ulvesli, 1955), sheep (Naerland, 1955), hogs (Hvidsten and Husby, 1955), and chickens (Njaa *et al.*, 1955)—in all cases with favorable results. Nitrite in concentrations ten times higher could be fed for 3 to 4 months without harmful effects.

2. *Dry Silage*

A dry fish silage feed which can be sold in paper sacks and which has good keeping quality has been developed in Denmark. Sulfuric acid silage is mixed with drier materials, such as wheat bran and alfalfa meal, the resulting mixtures containing 40 to 50% water. Mold growth is prevented by the addition of inhibitors (Anonymous, 1958c).

This solid silage mixture has a loose, crumbly consistency. One-half to three-quarters of such feed consists of wet fish. The water content varies between 40 and 60%. Usually this product has a pH of 3.5 to 4.

According to Bertullo (1958), silage is superior to fish meal. All thermolabile vitamins are saved. No minerals or protein are lost in the manufacturing. Furthermore, ensilage requires no expensive installations and can be carried out by individual fishermen. On the other hand, the disadvantage of silage is its higher moisture content, which on a weight basis reduces the content of essential nutrients. It is more difficult to handle, transport and store. In 1957, the Uruguayan production of fish silage was 500 metric tons and was expected to grow appreciably (Bertullo, 1958).

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CHAPTER 10

Fish in the Raising of Mink

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I. In the Ranch Diet

A. IN THE NATURAL DIET

A major part of the fat, protein, and mineral content of the world's commercial mink ranch diet is provided by fish and fish products. As a rough estimate it can be stated that ranch mink consume over one-third of a billion pounds of fish and fish scrap annually.

Examination of the visceral tracts of wild mink is one means of obtaining an indication of the dietary tastes of the mink. Studies of this type have shown that fish and crayfish comprise approximately one-third of the natural diet of the mink (Hamilton, 1936; Høie, 1954). Mammals (mice, muskrats, rabbits, and moles), birds, insects, and reptiles complete the diet of the mink in the wild.

B. IN THE COMMERCIAL RANCH DIET

Geographic and economic factors determine the composition of the mink's diet on the commercial mink ranch. Such ranches located near abundant sources of fish will use diets containing a high proportion of fish and fish scrap. Inland mink ranch diets generally contain a small proportion of fish products and a high percentage of beef, pork, and poultry by-products. For example, the mink rancher located on the

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Pacific coast of North America may feed a diet containing 10% cereal mix, 5% liver, 15% meat products, and 70% fish and fish scrap. On the other hand, the mink rancher located in the midwestern United States will usually use a diet made up of 20% cereal mix, 10% liver, 20% tripe (beef rumen), 25% fish, and 25% horsemeat, rabbits, and poultry by-products. A similar relationship between the composition of the mink ranch diet and geographic area has been noted in Norway (Rimeslatten, 1958). The species of fish present in the commercial mink ranch diet, as well as the percentage of fish in that diet, is determined by geographic factors. The utilization of fresh-water fish in the mink's diet is primarily limited to ranches of inland North America. Salt-water fish are used extensively on mink ranches in Japan, the Scandinavian countries, and the Atlantic and Pacific coastal areas of the United States and Canada.

1. *Fresh-Water Fish*

In order of their relative importance to the mink industry, the most common species of fresh-water fish used on North American mink ranches are: fresh-water smelt (*Osmerus mordax*), Lake Superior herring (*Leucichthys artedi*), sheepshead (*Aplodinotus grunniens*), carp (*Cyprinus carpio*), Lake Michigan chub (*Leucichthys artedi*), blue pike (*Stizostedion vitreum glaucum*), yellow perch (*Perca flavescens*), burbot (*Lota lota maculosa*), black bullhead (*Ameiurus melas*), sucker (*Catostomus commersonnii*), and alewife (*Pomolobus pseudoharengus*). The majority of these fish species are cooked prior to feeding to the mink. Cooking of these fish is necessary for the destruction of the thiamine- (vitamin B_1) destroying enzyme present in these fish. Lake Superior herring, sheepshead, Lake Michigan chub, blue pike, and yellow perch are nonthiaminase fish and therefore are not generally cooked before feeding to the mink.

2. *Salt-Water Fish*

More than half of the mink feed used by the world's mink industry originates from the sea. In Japan the fish most widely used for mink feed are the flatfish (Pleuronectidae) (Inukai, 1958). The greater part of the fish and fish scrap used for mink feeding in Scandinavia comes from the cod family (Gadidae) (Rimeslatten, 1958). Fish used in Scandinavian mink ranch diets include: cod (*Gadus callarias*), haddock (*Gadus aeglefinus*), whiting (*Gadus merlangus*), coalfish (*Gadus virens*), herring (*Clupea harengus*), mackerel (*Scomber scombrus*), stone biter (*Anarrhichas lupus*), lumpfish (*Cyclopterus lumpus*), and flounder (*Pleuronectes platessa*). The herring must be cooked before feeding to the mink because of the presence of the thiaminase enzyme. The fish scrap consists of the whole fish with the fillet and liver removed. The primary fish fed to the mink in the Atlantic coastal region of North America is the Atlantic whiting (*Merluccius bilinearis*). Small quantities of cod (*Gadus morrhua*), haddock (*Melanogrammus aeglefinus*) and rosefish (*Sebastes marinus*) are also fed to the mink. Mink ranchers on the Pacific coast of North America use many varieties of fish in their ranch diets. Fish used in this area include: turbot (*Atheresthes stomias*), red rockfish (*Sebastodes ruberrimus*), black rockfish (*Sebastodes melanops*), petrale sole (*Eopsetta jordani*), English sole (*Parophrys vetula*), slime sole or Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), sand sole (*Psettichthys melanostictus*), sand dab (*Citharichthys sordidus*), rosefish (*Sebastodes alutus*), and Pacific hake (*Merluccius productus*). Studies have been conducted at the Fur Animal Nutrition Laboratory at Oregon State College on the nutritional value of a number of these salt-water fish. Superior fur production has been noted in dark mink placed on diets containing high percentages of red rockfish or black rockfish. Turbot is an excellent fish for growth of the mink kits but is not satisfactory for fur production (Adair and Davis, 1957).

3. *Fish Meal*

At the present time only small quantities of fish meal are used in commercial mink ranch diets. Studies at the Royal Agricultural College, Vollebekk, Norway, have shown that it is possible to obtain good growth, fur production, and reproduction with mink on diets containing as much as 8% of a quality fish meal (Rimeslatten, 1958). Recent studies conducted in the United States indicate that excellent growth and fur production may be obtained with mink on ranch diets containing 6–7% of a quality fish meal (Leoschke, 1958b). In these experiments the fish meal contributed approximately one-fourth of the protein consumed by the mink. Digestibility studies with mink showed that the protein digestibility of the fish meal used in the experimental feeding trials was equal to that of Atlantic whiting (87.3%). These studies point toward an increased use of fish meal in the practical mink ranch diets of the future.

II. Nutritional Problems in Feeding Fish

A. CHASTEK PARALYSIS AND THE THIAMINASE ENZYME

A number of distinct nutritional problems have been found to be related to the feeding of fish to mink. The first important nutritional disease of fur-bearing animals related to the feeding of fish was noted on the fox ranch of J. S. Chastek of Glencoe, Minnesota, in 1932 (Green and Evans, 1940). Fox placed on a diet containing 18% frozen carp developed a paralysis within a few weeks and died. Research on the disease showed that it was of nutritional origin. The paralysis was the direct result of a thiamine (vitamin B_1) deficiency brought on by feeding fish containing a thiaminase (thiamine-destroying) enzyme. This was encountered in the carp. It not only destroyed thiamine in the fish body but also a significant portion of this vitamin present in other components of the ranch diet. A thorough study has been made on the distribution of the thiaminase enzyme in fish (Deutsch and Hasler, 1943). The enzyme seems to be confined primarily to certain types of freshwater fish. However, the taxonomic correlation as to presence or absence of this destructive factor within certain families of fish is not constant. Ocean herring is the only salt-water fish known to contain the thiaminase enzyme. The risks involved may, however, easily be removed either by the cooking of the fish or by following a planned feeding schedule. The majority of ranchers cook the fish at 180–200°F. for 15 min., which is required to destroy the thiaminase enzyme. Ranchers are able to use raw thiaminase fish if they limit the feeding of these fish to 2 or 3 days a week. Mink placed on this feeding program are able to obtain adequate thiamine from the diet on the days in which the diet does not contain thiaminase fish.

B. Yellow Fat Disease

An important mink disease of nutritional origin related, in part, to the feeding of fish is known as steatitis or the yellow fat disease. The disease affects only young mink and usually appears after weaning when the kits are consuming large quantities of food. Steatitis appears suddenly without warning. Mink kits may go off feed on one day and be dead on the following morning. Affected kits move with a peculiar, unsteady gait. At postmortem, the subcutaneous fat has a characteristic yellow-brown discoloration. There is a direct correlation between the incidence of yellow fat disease and the presence of rancid fish or horsemeat in the diet. Research studies have indicated that a low dietary level of vitamin E and a high dietary level of unsaturated fatty acids are prerequisites for the development of yellow fat disease in the kits (Gorham *et al.*, 1951; Lalor *et al.*, 1951). Horse fat and fish fat are potent sources of the unsaturated fatty acids. Yellow fat disease can be prevented by supplementing the diet with ample amounts of vitamin E (10–20 mg. of α-tocopherol per mink per day). Kits fed alewife, ocean herring, mackerel, and Lake Michigan chubs are particularly prone to the development of yellow fat disease (Belcher *et al.*, 1958; Rimeslatten, 1958). Mink fed large quantities of fish liver may also develop the disease.

C. Cotton Mink

In recent years a new nutritional disease has appeared to plague the mink industry. The disease is responsible for the development of cotton mink pelts. Cotton pelts are characterized by a depigmented (white), curly underfur. Preliminary studies indicate that cotton mink have low hemoglobin levels (Adair and Davis, 1957). In the United States the incidence of cotton mink has been correlated with the presence of large quantities of Atlantic whiting in the diet (Adair, 1956). In Norway the disease has been noted when the feed contains a high percentage of coalfish (Rimeslatten, 1958). Mink fed large quantities of fish liver may also develop cotton pelts. The exact nutritional factors responsible for the production of cotton mink are unknown. When cooked Atlantic whiting or coalfish is used cotton pelts do not develop. In a recent experiment, cotton mink were noted in a group of mink fed a diet containing 20% Pacific hake. However, cotton pelts were not produced in another group receiving a similar diet but containing eviscerated Pacific hake (Adair and Davis, 1957). It is possible that a heat-labile factor, bacterial or chemical, present in the intestinal tract of the Pacific hake was responsible for the production of the cotton pelts. Excellent quality pelts have been produced with mink on diets containing moderate levels (20–30%) of Atlantic whiting. Until the exact origin of this disease is known, it is recommended that the level of Atlantic whiting be limited to a maximum of 30% of the diet.

D. Fish and Fat in the Diet

The level of fat in the mink's diet is of critical importance in the economic production of quality pelts, this being the principal factor controlling the feed consumption. If the level of fat is too low, the amount of feed consumed is high and the growth of the kits retarded. On the other hand, if the level of fat is too high, the feed consumption of the mink may be restricted to the point of reducing the size and quality of the pelt. Experimental studies have shown that the optimum level of fat in the diet of the growing mink is 25% on a dehydrated basis (Leoschke, 1958a). The primary problem relative to mink ranch diets containing high levels of fish is generally one of the fat level being too low rather than too high. The problem of low-fat mink diets is especially common on mink ranches using large quantities of cod, haddock, Atlantic whiting, Pacific hake, fresh-water smelt, and sucker. Satisfactory fat levels may be maintained in these diets by the addition of tallow or lard to the diet. High-fat diets may be found on ranches using a high proportion of Lake Michigan chubs or turbot in the diet.

III. Handling Fish

A number of factors must be considered in the handling and processing of fish for distribution to and within the mink industry.

A. SANITATION

Rigid sanitary procedures are necessary in the processing of fish for mink feeding. A quality fish product can only be produced by careful handling and immediate freezing of the fish. Low palatability of the fish for the mink is the most common problem associated with unsanitary processing procedures. A correlation may exist between the improper preparation of fish for mink feeding and the disease known as cotton mink.

B. RANCID FISH

The development of rancidity in stored fish is one of the major difficulties of the present mink industry. Conditions easily become acute by the fact that the kits are particularly susceptible to yellow fat disease. This usually develops on ranches feeding fish or horsemeat that has been in storage for many months. However, the disease has been known to occur on mink ranches feeding fish stored for less than two months. Rancidity may be minimized by proper and rapid fish processing and by storage of the fish at low temperatures. Quality fish products should not be stored for more than three months prior to feeding. Although considerable thought has been given to the use of antioxidants in the processing of fish earmarked for mink feeding, no exact studies have been made on the problem at the present date. Yellow fat disease and fish products of low palatability for the mink are the direct consequences of suboptimal conditions for fish processing and in storage procedures.

C. PROCESSING OF FISH MEAL

Fish meal has not been used extensively within the mink industry. However, quality fish meal products are beginning to gain the attention of the mink rancher. The problem of heat damage of fish proteins during the processing of fish meal must be given primary consideration. Many studies have shown that certain amino acids present in proteins, especially lysine and arginine, are heat-labile (Allison, 1949). Heat processing methods may either result in actual destruction of these amino acids or may bind the amino acids within the protein in a manner which reduces their availability to the digestive processes of the animal's body. The problem of heat damage to proteins is of critical importance in the field of mink nutrition. The passage of food through the digestive system of the mink is completed in less than eight hours (Wood, 1956). Thus, it is essential that amino acids be readily available to the digestive enzymes of the mink. Recent experimental work has shown that arginine, a heat-labile amino acid, is of critical importance in the fur development of the mink (Leoschke and Elvehjem, 1954).

The stability of the fish oils present in fish meal is another problem to be considered in the processing of fish meal for the mink industry. The correlation between rancid fish fat and the yellow fat disease of the mink has already been stressed. The problem of the stability of fish oils present in fish meal may be resolved by the use of suitable antioxidants or, preferably, by the removal of the oils by solvent extraction procedures. Fat-stabilized fish meal and fat-free, solvent-extracted fish flour have been found to be equal in nutritional value to Atlantic whiting for the growth and fur production of the mink (Leoschke, 1958b).

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SANITATION

CHAPTER 11

Part I. Food Poisoning Caused by Fish and Fishery Products

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I. Introduction

Illness resulting from the ingestion of fish and fishery products can be due to a variety of causes. Some fish and shellfish in the live state are known to possess biotoxins which are not destroyed by cooking; well-known examples of such intoxications are the "fugu" or puffer poisoning of Japan and the paralytic shellfish poisoning of North America, Japan, and elsewhere.

Some people are known to be allergic to fish or shellfish, and this type of response is analogous to that caused by such other foodstuffs as eggs or strawberries. Illness can also result from the presence of food-poisoning bacteria (or their toxins), such as *Salmonella, Shigella, Staphylococcus* spp., and *Clostridium botulinum.* Intestinal upset can also result from the ingestion of spoiled fish where neither food-poisoning bacteria nor their toxins can be demonstrated, but where vagus-stimulatory compounds are said to be present.

Intoxications by poisonous fish and shellfish are dealt with adequately elsewhere in this volume and the present chapter will be concerned mainly with poisoning caused by bacterial action. Readers interested in allergy caused by fish and fish products are referred to the excellent articles by Halpern (1950) and Wenderoth (1956).

A. The Incidence of Poisoning with Fish and Fishery Products

It is unfortunate that reliable and up-to-date statistics on the incidence of food poisoning for countries outside England and Wales are very hard to come by, but the available information (Table I) shows

TABLE I

VEHICLES OF INFECTION IN GENERAL AND/OR FAMILY OUTBREAKS OF FOOD POISONING FOR WHICH DATA ARE AVAILABLE
(Expressed as % of Total)

			Meats			Fish				
Country and author	Year	No. of outbreaks (O) or cases (C)	Fresh	Processed	Canned	Fresh	Processed	Canned	Sweetmeats	Eggs
England and Wales (Cockburn and Vernon, 1957–1959)	1956	268 (O)	2.2	72.3	7.0	1.2	0.4	2.2	5.6	2.6
	1957	200 (O)	1.5	70.4	1.5	1.5	3.0	3.5	4.5	3.5
	1958	181 (O)	1.7	69.6	6.1	0.6	2.2	3.9	6.1	3.3
Italy (Bessler and Proja, 1957)	1955	246 (O)	—	19.1	10.2	—	—	16.7	4.1	—
	1956	163 (O)	—	18.4	7.4	—	—	20.2	5.5	—
Soviet Union (Krasnitskaya, 1958)	1956	No data		40.2[a]		7.3[b]		3.6	—	
Germany (Farchmin, 1950)	1949	84 (O)		48.8[a]			34.5[c]		—	2.4
Germany (Nord-Rhein-Westfalia) (Trüb and Reploh, 1954)	1946–1950	1980 (C) (including 21 mass infections with 1524 cases)	33.0	18.0	9.2	13.6	0.6[d]		—	9.0
East Germany (Farchmin, 1958)	1943–1957	840 (Incidents involving 10 or more people only)		57.9[a]			2.6[c]		0.5	2.3
United States (Dauer, 1958)	1957	235 (O)		40.4[a] (including 15.3 poultry)			<0.5[c]		10.2	—
Japan (Kawabata)[g]	1955	3277 (C)		1.6[a]			66.0[c]		—	0.8
	1956	1655 (C)		2.5[a]			51.7[c]		—	0.9

[a] Value for meats in general.

[b] Value for fresh and processed fish.

[c] Value for fish in general.

[d] Value for processed and canned fish.

TABLE I (*Continued*)

Country and author	Year	No. of outbreaks (O) or cases (C)	Milk		Cheese	Vegetables		Fruits	Pastries	Other foods
			Fresh	Dried		Fresh	Canned			
England and Wales (Cockburn and Vernon, 1957–1959)	1956	268 (O)	1.2	0.4	0.4	0.75	2.2	0.4	—	1.2
	1957	200 (O)	—	—	1.0	1.5	8.5	0.5	—	—
	1958	181 (O)	1.7	—	2.2	—	2.2	—	—	0.6
Italy (Bessler and Proja, 1957)	1955	246 (O)	—	0.4	8.1	—	—	—	18.3	23.1
	1956	163 (O)	—	5.5	8.0	—	—	—	20.2	14.7
Soviet Union (Krasnitskaya, 1958)	1956	No data	26.5[e]		—	—	—	—	—	22.4
Germany (Farchmin, 1950)	1949	84 (O)	—	—	—	—	—	—	—	14.3
Germany (Nord-Rhein-Westfalia) (Trüb and Reploh, 1954)	1946–1950	1980 (C) (including 21 mass infections with 1524 cases)	—	1.4	—	6.5[f]		—	1.5	6.3
East Germany (Farchmin, 1958)	1943–1957	840 (Incidents involving 10 or more people only)	—	—	—	3.5[f] (Salads)		—	—	32.8
United States (Dauer, 1958)	1957	235 (O)	—	—	—	6.4[f] (Salads)		—	—	40.4
Japan (Kawabata)[g]	1955	3277 (C)	1.0[e]		—	5.0[f]		—	—	27.3
	1956	1655 (C)	0.85[e]		—	10.0[f]		—	—	34.7

[e] Value for milk in general.

[f] Value for vegetables in general.

[g] See Chapter 11, Part II, in this volume.

some striking differences between the various countries. Thus, in the United Kingdom, North America and the Soviet Union, fish are relatively seldom incriminated—never more than 10%—whereas in Germany, Italy, and Japan, the figures range from 15 to more than 50%. This problem has also been discussed in quite some detail in a review by Meyer (1953). Various reasons can be advanced for such differences. Thus, the quantities of fish consumed in the various countries differ markedly. The latest available data (Anonymous, 1958) show that Scandinavia and Japan each consume about 20 kg. per capita per year, Germany and Britain about 7 to 10 kg., and the remaining European countries, along with Canada and the United States of America, about 3 to 6 kg. In areas with large consumption of fish, there is more chance of this article of diet being a vehicle of food poisoning than, say, milk. It is clear from the statistics, however, that this cannot be the whole story, since in Scandinavia food poisoning from fish and fishery products seldom occurs, whereas in Japan, with a comparable fish consumption per capita, over 50% of the cases of food poisoning are caused by fish and fishery products. In Japan, fish is prepared for the table in ways, seldom practiced in Scandinavia, which are likely to lead to bacterial infection and proliferation. Thus, "izushi," a most popular dish in some areas in Japan, made from raw fish, cooked and malted rice, diced vegetables, vinegar, salt, and spices, and allowed to ferment for 3 to 4 weeks, is a frequent cause of food poisoning (see Section II, C). The type of fish available is also important. Fish having biotoxins in the live flesh or edible organs are relatively abundant in tropical and subtropical waters (see Van Campen [1950] and Chapter 14 by Halstead), whereas poisonous fish are almost unknown in the North Atlantic and Arctic waters fished by Scandinavian, British, and other European fishermen (Shewan and Liston, 1955). In India dried bombay duck, "bombil," is a frequent source of poisoning (Bhat and Albuquerque, 1953).

The areas in which the fish are caught will also play a part. Fish, like shellfish, from polluted waters may well be infected with salmonellas and other food-poisoning types. Thus, the fish on Colombo market in Ceylon frequently carry *Salmonella* spp. (Gulasekharam *et al.*, 1956); and while some of this infection is undoubtedly due to unhygienic handling on board ship, part of it is believed to be the result of fishing in polluted coastal waters and lagoons. See also Brunner (1949) and Chapters 12 and 13 of this volume.

In the United Kingdom and Scandinavia and some other countries with a clean bill of health so far as fish are concerned, a major contributing factor is the temperature of the fish from catching to consumption. This is seldom above the range which allows the proliferation of most food-poisoning microorganisms, even if they chanced to be present. Recent information on fish temperatures during inland distribution in the United Kingdom (Burgess *et al.*, 1959) suggests, however, that, during the summer at least, the danger point is being reached in many instances.

II. Bacterial Food Poisoning

From the small amount of data available, it is clear that fish and fishery products can be the vehicle for all the more important types of bacterial food poisoning. These include not only salmonellas, staphylococci and *C. botulinum,* but also the so-called nonspecific group (*Escherichia coli, Proteus* spp., *Streptococcus faecalis, C. welchii* (*perfringens*), *Bacillus cereus,* etc.). It will be noted, however, that the cause of the majority of poisonings in most countries has remained undetected. It should also be stressed that the incidence of food poisoning from fish, as indeed from all foodstuffs, is probably much greater than that indicated in official statistics. Compulsory notification of food poisoning is not in force in all countries and not even in all of the United States. Hence, many incidents go unrecorded.

A. *Salmonella* AND *Shigella* INFECTIONS

All the available evidence shows that, unlike warm-blooded animals killed for human food, fish normally do not suffer from *Salmonella* or *Shigella* infections. As mentioned earlier, they may well carry these infections if caught in polluted waters (see Brunner, 1949; Reisler, 1952, p. 323, Moore, 1954, and Steiniger, 1951); but this risk is of much less importance in marine fish than in fresh-water species, where the dangers of pollution in rivers and lakes can be very real.

Thus, of the 97 fish, comprising 10 species, examined from the River Plate (Leiguarda *et al.*, 1950), 19.6% carried *Salmonella* spp.; 11% of the fish, mainly from the River Nile, on the Cairo market harbored salmonellas and shigellas (Floyd and Jones, 1954); and 6% of the fresh-water crayfish from Polish rivers and lakes were infected with *S. typhimurium* (Gaugusz and Malwinska, 1957). Bacillary dysentry has also been endemic for a long time in the region of the Great Lakes in Central Africa and, despite energetic prophylactic measures, persistent foci have remained (Jadin *et al.*, 1956, 1957). It has recently been established that the lake waters and about 2.0% of the fish caught therein carry both shigellas and salmonellas (Jadin *et al.*, 1956, 1957). Although it is not suggested that the fish suffer from these infections, they do appear to act as intermediate hosts for man, with the lakes themselves acting as immense reservoirs of bacillary dysentery. This is in marked contrast to fish caught in unpolluted lakes, e.g., in Canada (Margolis, 1952), where intestinal pathogens have not been encountered.

As already stated, fish caught in the open sea are free from salmonellas and shigellas. It is to be expected, however, that, once the fish have been handled on ship and on shore, some contamination from human sources is likely to ensue. Fecal contamination, as evidenced by the presence of *E. coli* and fecal streptococci, increases during handling and processing. In fillets and fish sticks, for example, the numbers of *E. coli* vary from 0 to 250/g. (Spencer, private communication; Shewan *et al.*, unpublished results; Ross and Thatcher, 1958); while the fecal streptococci may vary from 0 to 16,000/g. (Larkin *et al.*, 1956; Ross and Thatcher, 1958; Shewan *et al.*, unpublished results). However, despite a continued search for them, particularly over the past few years, neither shigellas nor salmonellas have ever been found at any stage of the distribution chain of marine fish in Britain (Shewan *et al.*, unpublished results 1958-59). As already mentioned, this is probably due to the time-temperature conditions during distribution being unsuitable for the growth of these pathogens even if contamination did occur at any one stage. Where conditions are suitable and contamination through a carrier or unsanitary handling does occur, then trouble can arise; and there are a sufficient number of well-documented incidents recorded in the literature to show that fish is no different in this respect from other foodstuffs (Müller, 1914; Bitter, 1920; Kapsenberg, 1938; Kleeman *et al.*, 1942; Ruys, 1948; Van den Broek, 1948; Olitzky *et al.*, 1956). Smoked fish has been particularly incriminated as a vector for salmonellas (Pivnick 1951).

In recent years, there has been an outburst of *Salmonella* epidemics, chiefly in West Germany, which could be traced to imported fish meal. These salmonellas spread to humans via livestock. Meal manufactured under primitive conditions in such warmer areas of the world as, e.g., Angola, more frequently carried these pathogens (Bischoff and Rohde, 1956; Rohde and Bischoff, 1956; Adam, 1957; Rohde *et al.*, 1958).

B. Staphylococcal Poisoning

As has already been mentioned in Chapter 15, Vol. I, micrococci form a regular, though usually small, part of the bacterial flora of newly caught fish. *Staphylococcus aureus,* however, is rarely encountered; and although Goethe (1957) recently found this organism, particularly in North Sea fish caught during the summer months, it is believed that the numbers present in relation to the total flora must be low (see also Dyer, 1947). It is perhaps not surprising that in a heavily fished area, where many vessels may be fishing together, a stenohyaline organism like *Staphylo-*

coccus aureus should be detected. While there may be some doubts as to the importance of staphylococcal contamination in newly caught fish, there can be little doubt that it is much less important than the subsequent infection during handling and processing on board ship and on shore. Almost 10–30% of the fish handled on board ship, filleted on shore, or purchased over the counter in the fresh, frozen, or processed state contain coagulase-positive *Staphylococcus aureus* (see also Abrahamson *et al.*, 1959). This is not surprising when it is recognized that 40% of the population harbor coagulase-positive staphylococci in the nose, and throat (Wilson, 1949; Ortel, 1958), although the percentage of these that are enterotoxic is unknown (Elek, 1959). In general, the levels of infection with coagulase-positive cocci are low and, provided the product is kept chilled or frozen during handling and distribution to the point of cooking, no health hazard ensues, since S. *aureus* cannot grow or produce its enterotoxin at temperatures below 4° to 6°C. (Dack and Segalove, 1941; Elek, 1959). Some danger might arise, however, during the manufacture of certain products such as fish sticks and fish cakes, where the temperature conditions are generally above the minimum for the growth of S. *aureus*. This almost certainly accounts for some of the recorded cases of poisoning arising from these products (Table II) (Kodama *et al.*, 1940; Abrahamson, 1958); but these dangers can be eliminated, provided the managements know the "hot spots" in their process and take suitable precautions to avoid them (Abrahamson, 1958).

Canned fish, it will be noted (Table II), are frequently incriminated in cases of staphylococcal food poisoning. In some instances this has been traced to infection during handling, coupled with time-temperature conditions in the factory which allowed the growth of S. *aureus* before heat-processing, and possibly subsequent faulty heat-processing (Ortel, 1958; Boyer *et al.*, 1951). In other incidents, the incriminating micrococci were found in the fish intestines and not on the surfaces or gills. For these and other reasons, it was believed that the cocci originated in the fish and not from human contamination (Goret and Joubert, 1958).

It has to be remembered that S. *aureus* enterotoxin is comparatively heat-stable (Dack, 1944; Jordan, 1930; Jordan *et al.*, 1931; Woolpert and Dack, 1933), so that retort heating in some cases might be insufficient to destroy all the toxin formed prior to heat-processing. In most cases where canned fish have been incriminated, the tins were not blown—S. *aureus* does not form gaseous products—nor, apparently, did they show any abnormalities in appearance, odor, or taste (Boyer *et al.*, 1951; Goret and Joubert, 1958). If the public is to be protected from such poisonings, it is essential, therefore, that managements should avoid conditions during processing likely to favor the growth of S. *aureus,* and that heat-processing itself should be adequate.

TABLE II

Recorded Incidents of Staphylococcal Poisoning Involving Fish and Fishery Products

Reference	Country	Product
Meyer (1934)	United States	Kippers
Kodama *et al.* (1940)	Japan	Fish sausage
Rutherford (1945)	Canada	Fish
Kjøs-Hansen (1946)	Norway	Fish pudding
Hussemann and Tanner (1947)	United States	Boiled salmon
Kjøs-Hansen (1948)	Norway	Lightly salted and smoked mackerel
Ødegaard and Lerche (1948)	Norway	Canned shrimps
Turjetzkii (1949)	Leningrad	Canned smoked cod, and sprats in oil
Boyer *et al.* (1951)	France	Sardines in oil
Boyer *et al.* (1952)	France	North African sardines in oil
de Casto Soares *et al.* (1953)	Spain	Bream in mayonnaise
Masi *et al.* (1959)	Puerto Rico	Salted codfish
Goldberg (1956)	Russia	Weakly salted herring
Ortel (1958)	Germany	Canned buckling in oil
Goret and Joubert (1958)	France	Moroccan sardines in oil
Cockburn and Vernon (1958)	Great Britain	Canned fish
Abrahamson (1958)	New York, United States	Frozen codfish cake

Salted fish has also been incriminated in staphylococcal food poisoning (Masi *et al.,* 1959); this is not surprising when it is remembered that salted fish, particularly in the dried state, may be stored for long periods at ordinary room temperatures, and that S. *aureus,* given suitable nutrients and moisture conditions, can grow even in high concentrations of salt (Evans and Niven, 1950; Chapman, 1945; Boury, 1932). It also seems likely that many of the previously recorded cases of poisoning due to the so-called "pink"-spoiled salted whitefish (Mauriac, 1886) were of staphylococcal origin and not caused by the "pink" halophilic bacteria, which are now known to be nonpathogenic.

In the Soviet Union, the most common staphylococcal poisoning seems to be through various fishes (cod, sprat, etc.) packed in oil—46.3% of all such poisoning cases (Turjetskii, 1949; Reisler, 1952, 1957).

C. BOTULISM

Although botulism is rarely encountered in some countries—in the United Kingdom only one case, involving pickled fish (Mackay-Scollay, 1958), has been recorded since 1935—a glance at Table III shows that, in others, sea foods are comparatively frequently incriminated. See also Meyer (1953) and Behre (1955). This is particularly the case in Japan, and also apparently in Russia, where botulism associated with fish and fishery products has been endemic for many years (Zlatagoroff and Soloviev, 1937; Zavadovskaya, 1940; Steinberg and Bier, 1937; Matviev, 1949). According to Ebert (1954), thousands of cases used to appear in Russia at the Lenten period, which were caused chiefly by salted fish products. Meyer (1953) has some doubt if all these incidents can be attributed to botulism. In almost all cases, it is items such as smoked or salted herring, salmon, sturgeon, caviar, or marinated or fermented products (Japanese "izushi"), all eaten uncooked, which are involved. Lerche *et al.* (1942) discuss six documented cases in Germany from 1931 to 1934, implicating several types and species of fish. Smoked salmon is reported to have caused botulinus poisoning in 1938; and marinated herring to have done so in 1940. Fish sausages carried botulinus in a 1949 can (Möller, 1949).

All botulism poisonings reported from Denmark, Norway, and Sweden from 1901 to 1946 (30 cases) were due to fish prepared in various ways (Dyggve, 1946). In commenting on this, Wundram and Schönberg refute the idea of this type of poisoning being considered particularly as a specific sausage poisoning.

The most striking feature of botulism arising from sea foods is that type E is almost always involved. Thus, of the 48 recorded cases with type E (Table III), only one is not a sea food (canned mushrooms). This type E was actually described by Prévot as a strain specific to the intestinal system of fish. Type E was also isolated in France from the intestinal content of perch (Prévot and Huet, 1951). The Soviet Public Health Institute in a study by Erismana encountered botulinus, type not specified, in the intestines of 5.4% of 130 sturgeon and 6.9% of 103 other fresh-water fish (Reisler, 1957). It is particularly spread around when hooks are used that penetrate the flesh and reach into the intestines, so their prevalence increases after handling (Reisler, 1952, 1957).

The reasons for the predilection of fish as a vehicle of type E botulism are now becoming clearer as a result of the researches of Dolman and several Japanese workers. The evidence is that marine and other aquatic environments, particularly in certain areas in the Northern Hemisphere, favor the existence of type E. Thus, of the 47 mud samples collected off

TABLE III

RECORDED ISOLATIONS OR OCCURRENCES OF *Clostridium botulinum* TYPE E

Year	Author and date	Place	Source
1932	Mackenzie (1934) (see also Hazen, 1942)	Cooperstown, N.Y., U.S.A.	Smoked salmon from Nova Scotia and/or Labrador
1934	Hazen (1937)	Westchester County, N.Y., U.S.A.	German commercially canned sprats
1934	Kushnir (1937)	Sea of Azov, U.S.S.R.	Intestines of "red" fish
1935	Kurochkin and Emelyanshik (1937)	U.S.S.R.	Salted sturgeon
1935-36	Gunnison *et al.* (1936)	Ukraine, U.S.S.R.	Muscle and intestines of sturgeon
1938	Hazen (1938)	Westchester County, N.Y., U.S.A.	Smoked salmon from Canada
1938	Zavadovskaya, 1940)	Leningrad, U.S.S.R.	Smoked herring
1941	Geiger (1941)	San Francisco, U.S.A.	Yugoslav mushrooms canned in California
1944	Dolman & Kerr (1947)	Nanaimo, B.C., Canada	Home-canned salmon (also home-canned chicken and soil of chicken run)
1949	Dolman *et al.* (1950)	Vancouver, B.C., Canada	Home-pickled herring
1950	Meyer and Eddie (1951) Dolman and Chang (1953)	Point Hope, Alaska, U.S.A.	Uncooked beluga (white whale) flippers
1951	Prévot and Huet (1951)	North-Central France	Intestines of fresh-water perch
1951	Prévot *et al.* (1952a)	France	Home-preserved tunny
1951	Pedersen (1953, 1955)	Denmark	Vinegared herring
1952	Prévot *et al.* (1952b)	Paris	Canned tunny
1952	Dolman (1953)	Natal, B.C., Canada	Home-pickled trout
1953	Sakaguchi *et al.* (1954)	Akita, Japan	"Izushi"—gilthead

TABLE III (*continued*)

Year	Author and date	Place	Source
1953-58	Komatsu *et al.* (1958) (quoted by Kawabata[a])	Japan	Fish and fish products
1954	Saito, Fujisawa, and Wada (1954) (quoted by Kawabata[a])	Termo Japan	Semipreserve of *Sparus*
1954	Dolman *et al.* (1955)	B.C., Canada	Salmon-egg cheese
1956	Meyer (quoted by Dolman, 1957a)	Anchorage, Alaska	Beluga (white whale)
1956	Dolman (1957a)	Nain, Labrador	Seal flipper
1956	Brocklehurst (1957)	Labrador	Seal flipper
1957	Dolman *et al.* (1959)	Prince Rupert, B.C., Canada	Raw salmon eggs
1957	Dolman (1957b)	Vancouver	Intestines of chum salmon purchased at fish dock
1951-57	Iida *et al.* (1958)	Hokkaido, Japan	"Izushi" made from raw fish

[a] See Chapter 11, Part II, in this volume.

TABLE IV

RECORDED INCIDENTS OF BOTULISM CAUSED BY THE INGESTION OF FISH OR FISHERY PRODUCTS NOT INVOLVING KNOWN CASES OF TYPE E

Year	Author	Place	Product involved
Type A			
1. 1899–1949 (also B and Unspecified)	Meyer and Eddie (1950)	United States	Mainly home-canned salmon, tuna, clams, sardines, but includes commercial packs (1 salmon, 1 tuna, 4 clams, 3 sardines and 1 crab)
2. 1934–1936 (also B & C)	Quoted by Kurochkin and Emelyanschik (1937)	Soviet Union	Salted or smoke-cured sturgeon, "redfish," and "white fish"
3. 1945–1948 (also Unspecified)	Wasmuth (1948)	Kiel and Schleswig, Germany	Mainly fish pickled in vinegar, but may include meats
4. 1955	Mackay-Scollay (1958)	Great Britain	"Barvis" made in Mauritius
5. 1957	Lubertino (1958)	Buenos Aires	"Antipasto" containing fish, lettuce, tomato, etc. Anchovies
6. 1958	Pereiro-Filho (1958)	Brazil	Canned fish
Type B			
1. 1899–1949	See Type A, No. 1		
2. 1934–1936	See Type A, No. 2		
3.	Vincent (quoted by Prévot *et al.*, 1953)	France	Marinated herring
4. 1940–1944	Skulberg (1958) (see also Bjerke *et al.*, 1959)	Oslo, Norway	Rakefish (pickled trout)
5. 1958	Dolman *et al.* (1959)	Near Prince Rupert, B.C., Canada	Fried fish eggs
6. 1958	Legroux *et al.* (1945)	France	Soup made out of tuna fish

TABLE IV (*continued*)

Year	Author	Place	Product involved
Type C			
1. 1934–1936	See Type A, No. 2		
Unspecified			
1. 1818–1913	Matviev (1949)	Soviet Union	Various products such as salted and smoked sturgeon, bream, herring and "white fish"
2. 1920–1926	Zlatagoroff and Soloviev (1927)	Soviet Union	(As above)
3. 1899–1949	See Type A, No. 1		
4. 1901–1946	Pedersen (1953)	Denmark	Desalted mackerel, herring, and canned salmon
5. 1930–1934	Minervin (1934) (see Zavadovskaya, 1940)	Ukraine	"Red" fish, smoked and salted herring, pike and bream
6. 1936	Freedman (1936) (see Zavadovskaya, 1940)	Soviet Union	"Red" fish
7. 1940	Dolman (1953)	Whitehouse, Yukon	Uncooked salmon eggs
8. 1941	Dolman (1953)	Maple Creek, Saskatchewan	Home canned fish
9. 1945–1948	See Type A No. 3		
10. 1946–1952	Ketz (1956)	East Germany	Product not stated
11. 1947–1952	Harmsen (1954)	West Germany	Smoked and pickled herring, home acid pickled cod, fish sausage and herring in jelly
	Knothe (1948) quoted by Harmsen	Hamburg	Acid pickled herring and fish
	Moeller (1949) quoted by Harmsen	Frankfurt	Fish sausage
	Mumme (quoted by Harmsen)	Hamburg	Acid-cured herring
12. 1936–1947	Wylder (1948)	New Mexico	Sardines
13. 1948	(Quoted by Meyer, 1956)	Germany	Products not stated
14. 1949	Farchmin (1950)	West Germany	Products not stated

the coast of British Columbia from depths ranging from 140 to over 700 meters, 6 yielded toxic cultures of type E (Dolman, 1957b). One out of four sea muds trawled from 350 to 400 meters off the southwest tip of Greenland was toxigenic (type E) (Pedersen, 1955), while 1.2% of the 2000 samples of lake and shore mud from Lake Abashiri and 10% of the sand from the Sea of Okhotsk, in Japan, yielded type E toxic cultures (Nakamura *et al.*, 1956). On the other hand, of 22 mud samples collected from Tasmanian and New South Wales coastal waters in Australia, type B, not type E, was demonstrated in two instances (Ohye and Scott, 1957). With more intensive sampling, however, the results in this latter case might have been different; and indeed, as Dolman (1957b) suggests, there is need for a more comprehensive survey in all parts of the world using isolation techniques which would take account of the peculiar properties of type E and, in particular, the low heat-resistance of its spores. Recent examinations in the author's laboratory of several samples of sea mud from the North Sea and the Arctic Ocean and 50 soil samples from the region of fish-working premises in Germany (Ebert, 1954) have all yielded negative results.

With *C. botulinum* type E in the muds and sands of the lakes and seas, it is not surprising that this microorganism should occasionally be present in fish caught in these areas, and this has now been well established by the work of Dolman (1957b), Nakamura *et al.* (1956), and Prévot and Huet (1951). *C. botulinum* has also been shown to be present in the muds, water, and fish caught in the area of the Sea of Azov in the Soviet Union, but in these instances the type is often not specified or is not type E (Burova *et al.*, 1935). Ebert could, furthermore, establish that type E was very common around fish-processing establishments in Bremerhaven. All soil samples collected in their vicinity contained this organism.

Another factor contributing to the incidence of type E botulism in fish and fishery products is that raw fish muscle provides a favorable medium for the generation, growth, and toxin production of this organism (Prévot and Brygoo, 1953); the fish carrying this organism can rapidly become poisonous at room temperatures. Indeed, toxin production can occur at a temperature just below 5°C. (Ohye and Scott, 1957) and in this respect type E differs from the others which form no toxin at temperatures below 10°C. (see Shewan and Liston, 1955). Pedersen (1953) reports that this E-strain becomes atoxic at 37°C. This goes well with the findings of Gunnison *et al.* that the Russian E-strains, isolated from fish, show a more reliable toxin production at room temperature than when grown at 37°C. Type E also differs in the relatively low heat-resistance of the spore. With types A, B, C, and D, these can survive heating from ½ to 5 hr. at 100°C. (see Shewan and Liston, 1953), whereas type E spores are inactivated by 20 min. at 80°C. (Nakamura *et al.*, 1956) or by 2 to 30 min. at 100°C. (Gunnison *et al.*, 1936; Dolman and Chang, 1953; Pederson, 1955).

Because of a case of botulinus poisoning through marinated herring in jelly, Meyer and Kietzmann (1958) devoted a special study to the pH relationships of different botulinus strains. They found type E more acid-resistant than the others. Below pH 5.3, growth is greatly retarded and no toxin is formed.

It should perhaps be added that botulism involving fish products is not confined exclusively to type E, and cases where other types are involved are listed in Table IV. One of the first monographs on botulinus by the Belgian scientist van Ermengem (1897) quotes a great number of German and Russian publications involving botulinus poisoning occurring in various preserved fish products. They appear to be of the nonproteolytic type B, at any rate Ermengem's own cases seem to belong to this category, according to Meyer (1953). See also Harmsen (1954, 1955).

III. Food Poisoning Caused by Spoiling Fish

The question is frequently asked to what extent spoiled fish, in which none of the microorganisms usually associated with intestinal upset can be detected, is the cause of food poisoning. Anderson (1909) believed that there was a toxic principle in the flesh of spoiled or spoiling fish which caused gastroenteritis, although Savage (1921) later stated that there was little evidence to show that really spoiled fish were at all harmful. Moreover, it is known that some people, e.g., the Eskimos and some Orientals, eat fish only after it is "high." The picture is complicated by the fact that some workers believe that many cases of food poisoning in which none of the normal pathogens can be detected, apart possibly from certain members of the nonspecific groups, are in fact due to staphylococcal enterotoxin. Thus, Dolman (1943) showed experimentally that a sausage inoculated first with an enterotoxic strain of *S. aureus* and 24 hr. later with a harmless culture of *Proteus vulgaris*, on subsequent plating gave almost exclusively a culture of *Proteus*. Yet two volunteers who ate the remainder of the sausage suffered violent gastrointestinal disturbance. Kämpe (1946) reported *C. perfringens* in spoiled canned fish.

More recently, there has been a revival of Anderson's idea, particularly in Germany (Schönberg, 1949; Bock, 1950), that some toxic principle is present in spoiled fish, and evidence has been accumulating for some time now that in one group, which includes the tunny-mackerel species, no poisoning pathogens can be detected. At least 23 incidents, all involving the mackerel-tunny group, have been recorded. Because of the poisoning reactions closely resembling a histamine shock (with urticaria), clinicians have been led to seek for histamine or histamine-like substances in these incriminated foods. A special chapter of this volume is devoted to this intriguing problem (see Chapter 14).

Micrococci, forming enterotoxins, seem to be the most likely cause of poisoning in the dried Indian fish "bombil" (Bhat and Albuquerque, 1953). These bacteria are absent on the fresh fish but appear as a result of contamination in the handling.

IV. Haff or Yuksov Disease

As a final comment on poisoning caused by the ingestion of fish and fishery products, mention may be made of a curious illness, known as Haff or Yuksov disease, which can occur in the communities bordering some of the inland lakes of Northwest Europe, East Prussia (Wellmann, 1951), Finland (Berlin, 1948), Russia (Khnyunin, 1949; Basharina and Kurochkina, 1949), Sweden (Berlin, 1948), and, possibly in one case, on the shores of the southwest coast of Kyushu, Japan (McAlpine and Araki, 1958; Berlin, 1958) (Table V). The illness takes the form of sudden, often very acute, pains in the muscles of legs, arms, and back, usually within 24 hr. after eating such fish as perch, bream, roach, turbot, lake trout, etc. Later, the slightest touch or movement causes the patient to scream with pain. Vomiting can occur in some cases, and the urine always has a brownish-black color. Recovery is usually complete after 24 hr., and mortality is about 1%, mainly the result of renal complications. Examinations of the ooze, plankton, plants and water from the lakes, together with bacteriological analysis of the incriminated fish, have all given negative results. One interesting observation was that animals, including foxes, after eating the raw fish from these lakes, develop symptoms similar to those of the Chastek paralysis first observed in a silver-fox farm in America. This condition, it is known, can be produced by a vitamin B_1-deficient diet and certain fish, particularly carp, have been shown to possess a thiamin-inactivating principle (Green *et al.*, 1942, quoted by Berlin, 1958). Animals suffering from Chastek paralysis can be rapidly cured by large doses of thiamin. From this and other evidence, both Ågren (quoted by Berlin, 1948) and Berlin (1948) conclude that Haff disease may possibly be caused by a thiamin-inactivating factor occurring in the flesh and organs of the fish. Vinberg (1954), on the other hand, believes that Haff disease is due to a toxin derived from planktonic blue-green algae, many of which are known to be toxic and carried through the food chain. Luxuriant blooms of these

TABLE V

OCCURRENCE OF HAFF OR YUKSOV DISEASE

Author	Place of occurrence and date	Species of fish involved
Wellmann (1951)	Koningsberg Haff, East Prussia (1924–1928)	Eel, burbot, burbt liver, and pike
Berlin (1948)	Lake Onega, Karelia (1934)	Not stated
Khnyunin (1949)	In neighborhood of Yuksov Lake, Soviet Union (1934–1935)	Not stated
Berlin (1948)	Lake Ymsen, south of Mariestad, Skaraborg, Sweden (1942)	Perch, bream, roach, eel, and burbot
Basharina and Kurochkina (1949)	Villages of Ykshozero and Peski, on shores of Lake Ykshozero, Karelian Finnish Republic, Soviet Union	Perch, ruff, and *Coregonus* sp.
McAlpine and Araki (1958)	Minamata Bay, southwest Coast of Kyushu, Japan	Not stated

algae have been observed in years when outbreaks of Haff disease occurred. Randall (1958) has also accepted this interpretation in his critical review.

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CHAPTER 11

Part II. Fish-Borne Food Poisoning in Japan

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I. Introduction

From ancient times, fish and their products have been the most important animal protein source in the Japanese diet. This is attributed to the geographical location and economic factors. The surrounding waters carry an abundance of fish and other sea food. The mountainous topography, on the other hand, makes the raising of livestock precarious. The taboo on eating cattle, dating many hundreds of years back, seems to some extent to have affected eating habits, particularly in rural regions.

Fish consumption is, however, hampered by poisonings that constitute a hazard to public health. According to statistical data (Table I), more than 60% of all such outbreaks refer to fish or fish products.

Table I lists the causative agents in recent outbreaks. Surprisingly many outbreaks remain undiagnosed. Clinical and epidemiological data, including the incubation period, symptoms, prevailing seasons, etc., clearly suggest that most of these cases are of a bacterial nature.

II. Bacterial Poisonings

Salmonellas and staphylococci are most common in this group. Much attention has recently been given to cases of botulism of type E from Hokkaido (Nakamura *et al.*, 1956), other northern parts of Honshu, and the main island (Sakaguchi *et al.*, 1954). Some outbreaks can be at-

TABLE I

OUTBREAKS OF FOOD POISONING IN RESPONSE TO CAUSATIVE AGENTS IN THE PERIOD 1957–1958

Causative agent	1957			1958		
	Cases	Patients	Deaths	Cases	Patients	Deaths
Bacteria	153	7,411	24	218	8,158	16
Salmonella	47	2,330	8	63	2,044	7
Staphylococcus	45	1,962	1	43	987	—
C. botulinum	3	49	9	—	—	—
Unidentified	58	3,070	6	112	5,127	9
Chemicals	11	69	6	13	304	5
Methanol	3	3	2	1	4	2
Others	8	66	4	12	300	3
Naturally occurring poisons	249	821	144	287	778	200
Plants	91	480	8	96	473	22
Animals	158	341	136	191	305	177
Unidentified	1,303	15,863	126	1,393	21,816	111

tributed to halophilic bacteria (Takigawa and Fujisawa, 1956). As shown in Table II, the number of outbreaks caused by the consumption of fish, shellfish, or other marine products accounts for more than 50 to 60% of the bacterial poisonings. This high frequency may be due to one or more of the following causes: (1) the preference for fish or shellfish in the raw stage. Numerous outbreaks are in fact attributed to raw fish. Some fish products, such as broiled, steamed, or fried fish paste products ("kamaboko," "hanpen," etc.) which are also consumed without further cooking are incriminated. (2) The low price of sea food as compared to other animal products. (3) The high degree of perishability combined with the time from capture to final consumption. Refrigerators are not very common, especially in rural districts. Furthermore, most people prefer fresh fish flesh to frozen. Most of the poisoning outbreaks have been due to improper handling or inefficient preservation.

III. Naturally Occurring Poisons

As to the classification of poisonings caused by naturally occurring poisons of various kinds, reference is made to Chapter 14, by Halstead. This presentation will restrict itself to some recent Japanese investigations in this field.

A. Tetraodon Poisoning

Globefish, "fugu," is a favorite both in China and Japan, but numerous poisonings have been reported. In some prefectures in Japan, a cook must have a license to cook and serve this fish to the public, while in others the sale of visceral organs is prohibited. Poisoning scarcely occurs from eating globefish at a restaurant; however, more than 200 cases, with 70 deaths, of this poisoning have been reported annually from eating home-cooked globefish.

In Japan, about 13 out of 27 known species of globefish are most commonly consumed, of which only saba-fugu (*Liosaccus lunaris* Bloch and Schneider) and yaito-fugu (*L. cutanus* Gunther) are nontoxic. Symptoms and other characteristics of fish poisoning are discussed in Chapter 14, Volume I.

Several investigations of globefish poisonings have been conducted by Japanese scientists. Tani (1945) revealed that there exists a marked seasonal difference with respect to toxicity, which is highest during the spawning period from December up to March. Since most globefish are eaten during the winter, this period coincides with the peak of the poisoning risks.

Toxicity differs greatly with species. The muscles, as well as the milt, are generally considered nontoxic or only slightly toxic, while the ovaries

TABLE II

OUTBREAKS OF FOOD POISONING IN RESPONSE TO VARIETY OF FOODSTUFFS IN THE PERIOD 1956–1958[a]

	1956			1957			1958		
Incriminated foodstuffs	Cases	Patients	Deaths	Cases	Patients	Deaths	Cases	Patients	Deaths
Fish and shellfish total	655	7,364	148	729	6,382	181	778	7,280	217
Shellfish	50	1,131	2	48	505	8	70	1,201	3
Globefish	127	185	107	157	241	137	187	289	176
Others	478	6,048	39	524	5,637	36	521	5,790	38
Fish products, total	200	3,197	32	185	1,796	27	225	4,923	23
Fish cakes	106	1,600	6	83	942	3	123	3,043	11
Others	94	1,597	26	102	855	24	102	1,880	12
Meat and meat products	41	1,057	2	36	1,175	5	49	1,444	2
Egg and egg products	15	301	6	15	385	1	12	285	1
Milk and dairy products	14	505	1	14	157	2	12	541	—
Cereals	94	1,772	9	87	1,354	5	81	1,279	4
Vegetables and beans	166	2,207	19	142	998	13	160	2,256	24
Miscellaneous	196	4,643	27	194	5,387	26	240	5,129	29
Unidentified	284	7,240	27	314	6,529	40	354	7,919	34
	1,655	22,286	271	1,716	24,164	300	1,911	31,056	332

[a] Figures cited were based on the data collected by the Food Sanitation Section, Public Health Bureau, Ministry of Welfare.

are lethal in doses as low as 2 g. of such tissue. Intestines follow the liver and ovaries in degree of toxicity. Sometimes the skin has turned out to be very dangerous and has caused poisonings. A few species seem to carry the poison in the muscle tissue. They are generally characterized by a reddish-brown skin and an extremely high toxicity. Other species with the poison chiefly in the viscera, as a rule, have a black or bluish-green skin. Quite different compounds have been isolated and been claimed to be the globefish poison (Tahara, 1910; Yokoo, 1950, 1952; Tsuda *et al.*, 1952a, b, and 1953) and there is quite some diversity of opinion as to its identity.

B. BARRACUDA POISONING

The great barracuda (*Sphyraena picuda* Bloch and Schneider) mingles with tuna in long-line fishing frequently in the tropical Pacific. An outbreak caused by this species occurred in Tokyo in 1947. Thirty people developed the typical symptoms (see Chapter 11, Part I). No deaths were recorded.

Hashimoto (1956) maintains there is a marked difference between the toxins involved in the tetraodon and the barracuda poisoning. The former attacks mainly the nerve endings, both motor and sensory, while the latter directly affects the central nerve system.

Several outbreaks have been reported from eating the liver of such species as “ishinagi” (*Stereolepis ischinagi*) (Abe *et al.*, 1957), Spanish mackerel (*Scomberomorus maculatus* A.) (Mizuta and Mizobe, 1957), and shark. In 1956, seven outbreaks of ishinagi poisoning occurred from eating the liver, in which case 21 persons developed symptoms. The poisoning is characterized by severe headache, nausea, and vomiting appearing from 30 min. to 12 hr. after ingestion. The temperature rises and some patients develop diarrhea, abdominal pain, and palpitation. In 1 to 2 days, a marked swelling appears on the face, followed by peeling of the skin, especially around the lips, nose, and neck. This peeling spreads all over the head, fingertips, arms, breast, and abdomen, and finally reaches the legs and toes. In no case is tingling or numbness recorded. Most cases recovered within 1 week, but peeling persisted. The causative agent or agents remain to be identified. The peeling may be indicative of an overdosage of vitamin A.

IV. Invertebrate Poisoning

A. VENERUPIN POISONING

In March, 1942, an outbreak of peculiar poisoning occurred near Lake Hamana, Shizuoka Prefecture, due to consumption of the clam “asari” (*Venerupis semidecussata* Reeve). Three hundred and twenty-four persons were affected, and 114 deaths (34%) occurred. In March, 1943, an essentially identical type of poisoning followed the eating of oysters (*Ostrea gigas*). In March, 1949, similar outbreaks involving 93 cases with 6 deaths (6.5%) occurred in the same district from eating "asari" and oysters. The first death ascribed to a similar shellfish poisoning occurred in 1889 in the district of Nagai-machi, Miura Peninsula. However, no case of similar poisonings has been reported from other countries. Symptoms and the isolation of the likely poisoning agent, venerupin, are discussed in Chapter 11, Part I.

In spite of a wide survey of Lake Hamana for bacteria, plankton, bottom material, or other environmental conditions, conducted by many investigators, the source of venerupin in shellfish has up to the present not been traced to its origin.

Shellfish toxicity in Lake Hamana is not on the same level throughout the year. The frequency peak has been recorded as located between March and April, followed by a rapid decrease to nontoxicity in the summer seasons. This poisoning is principally caused by clams and oysters, notwithstanding that "hamaguri" (*Meretrix meretrix lusoria* Roding) and "shiofuki" (*Mactra venerifirmis* Reeve) cultivated in the same part of Lake Hamana have never exhibited poisonous characteristics.

B. Paralytic Shellfish Poisoning

Outbreaks of paralytic shellfish poisoning are quite rare in Japan. Only one incident is known and that from July, 1948, in which the clam "asari" was toxic in the district of Yanagawa, Toyohashi, Shizuoka Prefecture (Hashimoto *et al.*, 1950). There were 12 cases, including one death with symptoms of shellfish poisoning identical to those in foreign countries. *Gonyaulax catenella*, considered the primary source of this poison, did not show any bloom, as "red tide."

C. "Ezowasure-gai" Poisoning

In 1950, an outbreak of shellfish poisoning was reported from the vicinity of Mori, Hokkaido Island, due to the eating of ezowasure-gai (*Callista brevisiphonata* Carpenter). Twenty-six people out of 115 consuming this particular species developed symptoms. No fatal case was encountered. Symptoms such as itching of the skin, nausea, blushing of the face, nettle rash, stomach ache, abdominal pain, stiffening, vomiting, asthma, and hoarseness, developed within 30 min. after ingestion of the incriminated shellfish. No relationship was established between the freshness of shellfish and the poisoning. Asano *et al.* (1950) reported that an unusual amount of choline was detected in the shellfish. He suggested that the allergy-like symptoms may have some relationship to overdosage of choline, abundant in the ovaries, either as choline or its esters. The amount of these compounds in the ovaries increases parallel with the state of maturity as the spawning period unfolds, and at the same time the toxicity increases.

D. "Hime-ezobora" Poisoning (Gastropod)

Many outbreaks of "hime-ezobora" (*Neptunea* (*Barbitonia*) *apthritica* Bernardi), a gastropod poisoning, have occurred in the island of Hokkaido. This gastropod, known to be one of the most delicious shellfish, is widely distributed in the coastal waters of this island. The poisoning is characterized by such symptoms as headache, dizziness, nausea, vomiting, and others within 30 min. after eating these gastropods. In some cases, nettle rash develops. The causative agent has not been identified as yet but, according to Asano (1952), it appears that the poison is a physiological metabolite, as the toxic substance exists only in the salivary gland and not in other organs. Removal of the salivary gland before eating would be an effective way to prevent intoxication. The poison is soluble in water or alcohol, but insoluble in chloroform or ether. It is a heat-stable substance and seems to belong to the amines rather than to the alkaloids.

V. Unusual Cephalopod and Fish Intoxications

During the years 1952–1955 a series of intoxications from squid occurred in Niigata, Yamagata, and Nagano Prefectures; 785 outbreaks were reported involving a total of 2,874 persons. From June to September, 1955, there were at least 108 outbreaks, with 2,159 diseased persons in Niigata Prefecture and the islands of Miyake, Mikura, and Hachijo caused by scombroid and carangoid fishes. The actual number of persons involved is believed to have been considerably greater than indicated [see further Kawabata *et al.* (1957)].

The squid causing the outbreak is "yariika" (*Ommastrephes sloani pacificus*). One case in Yamagata Prefecture was traced to squid captured in the vicinity of Tobishima Island about 35 km. northwest of the city of Sakata. Another outbreak in Niigata Prefecture originated with squids from the waters around Sado Island. Both these islands are located in the Japanese Sea. No poisonings resulted from squid simultaneously captured near Hachinohe in Aomori Prefecture, in an area bordering the Pacific Ocean.

Mackerel scad, "muro-aji," (*Decapterus muroadsi* T. and S.) and other related "aji" (*D. lajang* and *D. macrosoma*) causing poisonings in Miyake, Mikura, and Hachijo Islands, were captured in the vicinity of Mikura Island, off the south central coast of Honshu.

The Japanese horse mackerel, "maaji," common Japanese mackerel, "masaba," and flying fish, "tobiuwo" (*Prognichthys agoo*), were incriminated in outbreaks in Niigata Prefecture and captured along the coastal waters of that same region.

The symptomatology was essentially the same in all these cases, regardless of the poisoning species. The incubation period varied from 10 to 20 hr. The predominant symptoms consisted of nausea, vomiting, abdominal pain, diarrhea, fever (38–39 C.), headache, chills, and weakness. Most of the patients recovered within a period of about 48 hr. The largest series of fish intoxications, in which there were 4,511 known consumers and 1,113 victims developing symptoms, showed a mortality of 24.6%. In the most serious squid intoxications there were 2,202 consumers and 589 victims, or a death percentage of 27.1. Neurological symptoms were largely absent. Bacteriological examinations failed to show evidence of any of the ordinary types of bacteria known to cause food poisoning The putrefaction was no factor in this particular series of intoxications. Iwamoto *et al.* (1957) disclosed that serum cholinesterase activity in the patients of fish-borne summer food poisoning in 1956 was lower than that in normal healthy persons. However, the etiology of these outbreaks is still unknown.

Minamata Disease

During the past few years the inhabitants of the Island of Kyushu have been afflicted with an apparently new disease resulting from the ingestion of fish or shellfish. This neurological disease was named Minamata disease for the industrial town near which the patients resided (McAlpine and Araki, 1958). The first cases appeared toward the end of 1953. Fifty-six persons were finally afflicted with the disease. This number gradually increased through 1956, when a government edict was passed to prohibit fishing in the bay. Since then, no new cases have been reported. Minamata is the site of a large artificial fertilizer factory. Prior to 1950, the effluent from the factory was poured into the sea. At the latter date, a new sewer line was built which poured the water into Minamata Bay. It was not until three years later that the first neurological disorders were seen.

The first symptom was a numbness in the extremities and sometimes around the mouth, frequently followed by slurred speech, unsteady gait, and increasing disability. Deafness and disturbances of vision, the latter being confined to constriction of the visual field, were seen in most cases. Many patients experienced difficulty in speech, insomnia, and emotional disturbances. Mental confusion and muscular incoordination occurred in all cases. Seriously affected patients showed an increased amount of amino acids in the urine and of γ-globulin in the blood.

The mortality rate was 33%. Eight patients died within 2 months after the first symptoms, while four died within the first year. The other patients remained incapacitated to varying degrees. There apparently was no recovery once the individual was afflicted with Minamata disease. In autopsies, small necrotic areas were encountered in the intestinal mucosal membrane in the viscera. The central nervous system showed cellular degeneration which was most marked in the granular layer of the cerebellum; there was a dilation of the perivascular spaces, with occasional softening, but no demyelination. There was edema, and occasionally small hemorrhages also in the spinal cord.

Fishermen and their families were mainly affected, and the evidence supports the thesis that the disease was caused by eating fish from the bay. In many instances, two or more members of the same family had the disease. In the neighboring families where this disease did not appear, fish from the local bay was consumed either not at all or in very small amounts. All ages and both sexes were equally represented. Infants were protected, probably because they were breast-fed until the age of two.

The factor causing the neurological disturbances is unknown. It appears to be heat-stable, since some of the individuals who developed the disease ate nothing but cooked fish. Cats, crows, and possibly also such animals as pigs and dogs, appeared to be susceptible to a similar disease. The brains of ten cats that died of this condition showed changes similar to those observed in the human material. The disease could readily be produced by feeding fish from the bay during 2 to 4 weeks to cats (Anonymous, 1959).

Although the fish from the bay and effluents from the local factory showed increased amounts of manganese, selenium, and copper, the manifestations of the disease are not those normally associated with the toxicity of these elements. A large amount of biological and biochemical work has to be done before the factors causing this disease can be safely recognized.

VI. Allergy-like Poisonings

Allergy-like poisonings (Kawabata *et al.*, 1955a) develop in many fish and shellfish cases. Several such outbreaks are attributed to dried fish products such as "samma-sakuraboshi" (dried, seasoned saury). Attention was first drawn to these allergy-like food poisonings in 1951, when mass outbreaks occurred in Tokyo, and numerous consumers were affected. Since then, similar cases have been reported from many places, and several research workers have been greatly concerned with this disease.

The causative agent was for a long time identified with histamine. However, Aiiso (1954) recently demonstrated that although the same amount of histamine as 450–500 mg.% contained in the material of "samma-sakuraboshi," responsible for an outbreak in Hiroshima, did not produce any symptoms among human volunteers, this same fish product actually produced symptoms. From this fact, the following conclusion was drawn. There may have been some other poison or poisons in the incriminated material in addition to histamine, which occurred in unusual amount, or else there may have been some substance which may have intensified the histamine activity. Miyaki and Hayashi (1954) assumed that the poisoning might be caused by such a combined effect. They mentioned trimethylamine oxide, trimethylamine, phosphorylcholine, agmatine, etc., as such substances. Kawabata *et al.* (1955b, c) also investigated similar materials independently and confirmed the marked difference between the amount of histamine actually analyzed by a chemical method and that estimated from the rate of contraction of a strip of guinea pig intestine by means of the Magnus' method. The presence of a specific vagus stimulant, tentatively designated as "saurine" was assumed by Kawabata *et al.* (1955c). Unusual amounts af histamine were, however, also demonstrated. For a further discussion of this histamine problem, see Volume I, Chapter 10; an account is given there of the existence of special bacteria that may produce histamine.

VII. Fish-borne (Type E) Botulism

It was generally believed that *Clostridium botulinum* did not exist in Japan. No epidemiological or clinical cases of botulism had ever been recorded. In addition, a wide soil survey had failed to detect such spores.

The first known outbreak of type E botulism was reported in May, 1951, from Iwanai, Hokkaido Island, caused by the eating of "izushi." Fourteen persons developed symptoms and four died. Nakamura *et al.* (1956) isolated the causative bacteria as a type E *C. botulinum.*

One year later, two similar poisonings occurred on the island of Hokkaido; in both cases type E organisms were isolated. Since 1951, when the first case was reported by Nakamura *et al.*, the total number of such type E poisonings have amounted to 22, in which 168 persons were affected, of whom 50, or 31%, died (Komatsu *et al.*, 1958).

It is worth noting that all these Japanese cases refer to type E. As to the specifics of this class of poisonings reference is made to Chapter 11, Part I, by Shewan.

Nakamura *et al.* (1956) disclosed that type E is widely distributed in the soil, coastal sand, etc. They found its frequency to range from 0.4%

(one out of 247 soil samples from various districts in Hokkaido) to 4.0% (2 out of 40 samples of coastal sand by the Sea of Okhotsk).

Recent work in various laboratories indicates that type E toxin production in fish does not depend simply on appropriate temperatures and pH conditions but is specifically affected by such factors as the mutational phase of invading organisms, the presence of other bacterial contamination and the possible action of nonbacterial enzymes. With regard to mutational phases of type E, Dolman (1957b) revealed that there are three distinct phases: the heavily sporulating ("OS"); toxigenic ("TOX"); proteolytic ("TP") ones among type E organisms; the combination of "TOX" and "TP" greatly affects the toxic potency in the fish. Furthermore, Sakaguchi and Tohyama (1955) established the presence of a fellow contaminant, a proteolytic strain of the genus *Clostridium,* which promotes toxin production when grown together in mixed culture with a weakly toxigenic type E strain. The activation of type E toxin by trypsin was reported by Duff (1956). This indicates the possibility that the type E toxin could be activated in the digestive tracts of human victims. Proteolytic enzymes originating in fish organs or tissues may also increase the amount of toxin produced prior to consumption.

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CHAPTER 12

Polluted Waters and the Contamination of Fish

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I. Introduction

If it were true that the bacterial flora of a fish reflected the bacteriological conditions in the waters from which it originated, then the fish could be considered as an indication of the sanitary conditions of these waters. Because fish cover great distances in different waters, the bacteriological examination of their intestinal contents supplements in a good way the direct sampling of the waters. This interpretation immediately raises a number of questions of an ecological and physiological nature. Besides the fact that bacteria have a certain distribution pattern in waters of varying depths depending on the distance from outflowing contaminating rivers, it is essential to know if fish are subject to a contamination by the Enterobacteriaceae and if this group as a whole may constitute part of the bacterial flora of fish and, if not, how long these bacteria may survive in the digestive tract.

Enterobacteriaceae common to fish, or accidentally living in the digestive system for a prolonged period, may not furnish useful information regarding the actual sanitary state of the waters. The presence of these bacteria merely indicates that a contamination has taken place, but perhaps long ago, and has no relationship to conditions in the waters under study. Brown (1917), studying fish captured in nonpolluted waters, established the presence of *Escherichia coli* and *Welchia perfringens,* which could be interpreted in this way.

The publications from the last sixty years concerning the bacteriology of fish have either been inspired by sanitary precautions: by a desire to investigate the origin of bacterial contamination of commercial fishes or by the study of the problem of polluted waters. The presence of coliforms in a water is generally interpreted as a sign of fecal contamination and has been the prime object for study. A few investigations deal with *Escherichia paracoli* or *Proteus* but rarely *Salmonella* or *Welchia perfringens.*

In 1899 Hoag isolated *Escherichia coli* from the intestines of sea-water fish. Whipple (see Johnson, 1904) did not find this organism in 75 samples of sea-water fish from nonpolluted waters. Amyot (1901) obtained positive results with 23 samples. Kister and later Mallanah (unpublished results, referred to by Fromme, 1910), the former on the basis of 21 samples and the latter with 32 fish samples, reached identical results. Houston (1903, 1904) found 13% containing *E. coli* and drew the conclusion that this was due to a contamination of the water through sewage. Eyre *et al.* (1904) considered *E. coli* as a normal inhabitant of fish intestine. His material was collected two metric miles from the coast. Johnson (1904) observed *E. coli* 47 times out of 67 and assumed that fish carried this organism from contaminated waters out into clean waters. Bettencourt and Borges (1908b) indicated two cases of coliforms out of 17 fish. Fromme (1910) found 18 out of 33 fish contaminated. Browne (1917) studied fish living in nonpolluted waters and established that 59% harbored *E. coli* and *Welchia perfringens.* Hunter (1922) isolated *E. coli* and *Aerobacter areogenes* from the intestines of salmon. Stutzer (1926) considered *E. coli* and *B. paracoli* as part of the normal flora of fish intestines. Fellers (1926) showed that the digestive system of salmon contained no *E. coli.* Reed and Spence (1929) found 70% of haddock containing *Proteus,* but *E. coli* was extremely rare. Stewart (1932), too, was unable to detect *E. coli* in haddock and found very few *Aerobacter.* Gibbons (1934a, b) indicated the presence of *Proteus* in 2 cases out of 43; only once was *Eberthella* met with. He did not consider the coliforms to be normal inhabitants of the digestive system of sea-water fish. When they were found, it was in fish which were contaminated by polluted water. Griffith and Fuller (1936) concluded, basing their studies on commercial fishes, that *E. coli* was presumably an external contaminant. Markoff (1939–1940) believes that the presence in fish viscera of bacteria belonging to the coli-typhus group shows that the fish have been staying for some time in polluted water. Sooner or later they get rid of these microorganisms. Snow and Beard (1939), studying 1838 bacterial cultures isolated from salmon, found *E. coli* in 0.1% of the cases. Wood (1940) found no coliforms in the different fish of Australian waters. Nor did ZoBell (1941, 1946) find this type of bacteria in studying 387 fishes and 961 samples of sea water; 5 cases of *E. coli* were observed in fish caught close to the coast. The *Aerobacter* are more frequent (13%) than the other coliforms (6%). According to ZoBell, it is not a habitual flora in fish but always an introduced flora which may persist for a considerable length of time. Fredericq (1950) studied the intestine of various marine animals in the bay of Villefranche and established the presence of Enterobacteriaceae in 37 fish. Guélin (1952b) isolated bacteria and enteric bacteriophages in fish captured in waters of the littoral zone exclusively. Margollis (1952) reports the presence of *E. coli* and *Proteus* in pikes intestine. Lodenkemper (1952) concludes that salmonellae in fish play the principal part in food poisonings. Venkatraman and Sreenivasan (1953) found *Paracolobacterium* in fresh-water fish. Floyd and Jones (1954), studying 376 lots of fish, revealed the presence of *Salmonella* in 11% of the lots. Jadin *et al.* (1957) discussed the possible transmission of *Shigella* and *Salmonella* by fish.

An analysis of all these observations reveals contradictory results in a few cases. Prior to 1926, particularly, authors frequently reported the isolation of enteric microorganisms. On the other hand, almost as many found none. Eyre *et al.* (1904) and Stutzer (1924) considered the enterobacteria as normal inhabitants in fish. Houston (1903), Johnson (1904), Fellers (1926), Gibbons (1934a, b), Markoff (1939–1940), ZoBell (1941), Guélin (1952b) and Jadin *et al.* (1957) reached the conclusion that fish became contaminated by the Enterobacteriaceae when exposed to polluted waters.

These contradictory results are explained by the absence of coordination in the study and by the development of our knowledge on *Escherichia* and Esch. like bacteria. As a matter of fact, the relative frequency of *Aeromonas* (Buttiaux, personal communication) in certain species of fish should not be overlooked. These germs, when a study of their cilial apparatus is neglected, are generally identified as *Paracolobacterium* or *Cloaca*. This also applies to the numerous strains of unpigmented *Ferratia* to which Ewing *et al.* (1959) justly have drawn attention. Therefore, different organisms have been studied and with varying methods, and on different species and from localities which frequently were very poorly defined. But as a whole the results show the accidental character of the presence of Enterobacteriaceae in fish.

In my personal studies of fish in 1951–1952, besides investigating the Enterobacteriaceae, I also executed observations on the intestinal bacteriophages. Since Dumas (1920) first established the presence of colidysenteric bacteriophages in the water of the river Seine, studies of bacteriophages in water have become more and more common. In France the practical application of bacteriophagic research to waters was the topic of a special government circular of November 24, 1954 (Névot, 1957; Parvis and Tarantini, 1958).

II. Enteric Bacteriophages in Water

In 1891, Siemens presented a hypothesis that bacteria were susceptible to infectious diseases caused by extremely small organisms. Gamaleia (1899) was the first to announce the lysis of bacteria and the ability of this lysate to dissolve a freshly prepared culture. Twort (1915) gave a detailed description of a transmissible lysis of staphylococci and supposed that the causative agent was a filterable virus. His observations, as well as those of Gamaleia, did not attract due attention and were not pursued. It was d'Hérelle (1917) who, after having obtained a lysis of the Shiga bacillus by *Bacteriophagum intestinale* (an agent which can be filtered), initiated a serious study of this agent. These classic investigations by d'Herelle were rapidly followed by similar studies by other authors and contribute the basis of our present knowledge of bacteriophages. Their more recent definition as "bacterial viruses" refers to the extremely small dimensions of their body (from 15 to 100 mμ in diameter) and to their ability to develop exclusively in living bacteria and there exhibit their growth phase. The bacteriophages attach themselves to the surface of the bacteria and soon afterwards start to increase in number, the more so as the bacteria gradually keep multiplying. But young bacteria which are attacked undergo lysis and the whole culture becomes completely transparent. Bacteriophages are found wherever bacteria are present; there are numerous varieties corresponding to a great number of bacterial species. Kriss (1959) revealed the presence of bacteriophages active on marine bacteria in the Black Sea. They have been isolated *in vitro* and in the waters down to a depth of 2,000 meters. (Kriss and Rukina, 1947; Spencer, 1955). In polluted waters, they are always found (Dumas, 1920; d'Hérelle, 1921; Hauduroy, 1923; Arloing and Chavanne, 1925; Arloing and Sempé, 1926a, b; Monteiro, 1926; Fabry, 1928; Morin and Guillerm, 1928; Gildemeister and Watanabe, 1931; Robic, 1937; Diénert *et al.*, 1934; Panayotatou, 1935; Klemparskaja, 1940; Rita, 1940; Vaccaro *et al.*, 1941). Bacteriophages may remain for long periods in river or sea waters without losing their specific activity against bacteria.

Assuming that bacteriophages are constant companions of bacteria and that their number vary according to the number of bacteria present, they can be looked upon as evidence of water pollution (Arnold, 1925; Fortunato, 1929; Renaux, 1929; Pasricha and Gupta, 1931; Vagedes, 1932; Diénert, 1934; Vagedes and Gildemeister, 1934; Couture, 1936; Ciuca and Cocioba, 1937; Cocioba, 1937, 1941; Rhodes and Ludlam, 1939; Abdelrachman, 1943; Guélin, 1943, 1948a, 1955; Guélin and Le Bris, 1947; Gernez–Rieux *et al.*, 1949; Buttiaux, 1949, 1951; Buczowski and Buczowska, 1951; Alva *et al.*, 1951; Leclerc, 1956, 1957, 1959; Parvis and Tarantini, 1958; Monnet *et al.*, 1958; Nicolle, 1959; Carlucci and Pramer, 1960d). Buttiaux considers the presence of "fecal bacteriophages" (according to his terminology) as a proof of dangerous contamination of water. The fecal pollution of waters at a distance of 1,000 meters from the sewage outflow in the estuary of the Rance (Atlantic) has been brought into evidence by the presence of these bacteriophages (Buttiaux, personal information, 1958). Verde (1958) published a complete survey on this subject. Penna (1959) tested 138 water samples, comparing the bacteriological method with the bacteriophage procedure. See also Chapter 13.

A. Bacteriophages as Indicators of the Presence of Pathogenic Bacteria in Water

It is still an open question if sea-water as such exerts a direct bactericidal effect without the aid of bacteriophages (ZoBell, 1936; Krassilnikov, 1938; Johannesson, 1957). Several good reviews on this question are available (Greenberg, 1956; Carlucci and Pramer, 1959). Although several enteric bacteria may create a health hazard when spread in sea-water, it is nevertheless well established that the rate of their disappearance is far greater that what could be expected from dilution alone. Undoubtedly the salinity and pH of sea-water do not favor the direct survival of *E. coli* (Carlucci and Pramer, 1960b), unless protected by organic pollution or certain mineral salts. This evidently is a causal factor of some significance. Heat-labile substances of an antibiotic nature have been repeatedly found in sea-water (ZoBell, 1936; Krassilnikov, 1938). Furthermore, marine microorganisms have been shown to produce such substances (Rosenfeld and ZoBell, 1947). In a recent study, however, no antibiotics were found exerting any particular influence on *E. coli* (Carlucci and Pramer, 1960c). This is in contradistinction with the findings of Johannesson (1957) who reported a clear bactericidal effect of sea water on *E. coli.* He indicated that the active agent was inorganic and identical to iodine. Evidently it is a question of definition if this inorganic compound should be listed as an antibiotic or merely a bactericidal agent. Coli bacteria could be protected against its killing action by small amounts of cysteine. Naturally this latter compound readily appears in polluted water or sewage effluents.

Among the so-called fecal bacteriophages isolated from water a large number bear evidence of a common fecal contamination. They can easily multiply at the expense of various enteric bacteria. Being very polyvalent they are of less interest from the point of view of water sanitation. Specific bacteriophages multiplying only at the expense of one special kind of bacteria can be used for detecting pathogenic microorganisms in water. Isolation of such typhi or *perfringens* phages from water can, for instance, justify the conclusion that these waters, at a given moment, were contaminated by typhic bacteria or by *Welchia perfringens*. The Vi bacteriophage, specifically active on *Salmonella* Vi (Scholtens, 1936; Sertic and Boulgakov, 1936; Craigie and Brandon, 1936), clearly reveals the presence of these bacteria (see Fig. 1).

fringens

The study of typical bacteriophages for the detection of *Salmonella* in waters has been recommended by Guélin and Le Bris (1947). Guélin (1948b) describes the method for isolating the bacteriophages Vi from waters. Gernez–Rieux *et al.* (1949) points out the importance of searching for these phages for the demonstration of Eberthellae. Morzycki *et al.* (1952) conclude in a study of the Vistula waters stretching over 427 kilometers, that the Vi bacteriophage can be regarded as a specific organism indicating the presence of typhic bacilli in the waters; the resistance of the phage in industrial waters (harmful to *E. coli*) makes it more valuable. Its human origin, shown by Morzycka and Georgiades (1952), gives it all the advantages in a study of water hygiene. This was confirmed by Alva *et al.* (1951), Leclerc (1956, 1957, 1959), Parvis and Tarantini (1958).

FIG. 1. Typhic bacteriophages of type Vi (after Guintini *et al.*, 1953).

During recent years, Timakov and Goldfarb (1956a, b), Goldfarb (1957, 1959), and Goldfarb and Erchov (1958) developed a bacteriophagic method for the detection of *Salmonella* and dysenteric bacteria in water. This method is not characterized by the kind of bacteriophages being employed but rather by the susceptibility of the various bacteria occurring in the water, increasing the proportion of specific standard phages. The bacteriophagic method is many thousand times more sensible than any direct bacteriological analysis (Timakov and Goldfarb, 1956b; Goldfarb and Ostrovskaja, 1957; Goldfarb and Kouznetzova, 1957; Abdouzamatov, 1959).

The presence of phages in water does not, however, automatically indicate how long it has been contaminated. The disappearance of the typhus bacilli is faster than that of the phage Vi (Guélin, 1950a; Buttiaux, 1951; Emilianowicz, 1952). Even if the prolonged sojourn of the bacteriophage Vi in water does not destroy its specificity toward the typhic strains (Guélin, 1948b, 1950a; Goldfarb and Ostrovskaja, 1957), its concentration gradually diminishes, particularly during the first few days. Factors such as temperature, solar radiation, the pH of the water, and the mineral content have a direct effect in this regard. So it is the quantity of isolated phages which makes it possible to establish approximately how old the contamination of the water is. When the specific bacteriophages are found in large quantities this indicates a rather recent pollution; on the contrary, their repeated isolation in small numbers indicates an older contamination.

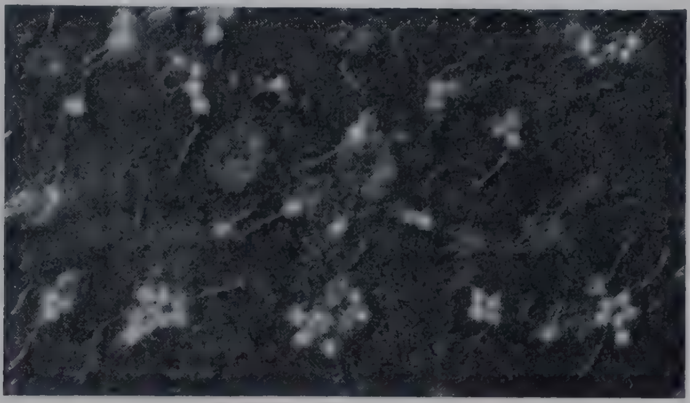

FIG. 2. Bacteriophages of *Welchia perfringens* (after Elford *et al.*, 1953).

Comparative studies in the Mediterranean, the Seine, and the Thames show that the bacteriophage count varies according to its type. Under the given conditions and when a typhic bacteriophage can be identified in 0.1–0.01 ml^3 water, it can be concluded that it is present in the water in large quantity. The same is true with the coli-phage isolated from 0.001–0.0001 ml^3, as well as with the phage of *W. perfringens* found in 1 ml^3 (Fig. 2). Differences in quantities of isolated phages found in one and the same water are most likely to run parallel with the frequency of the corresponding bacteria with which the water is polluted. *E. coli* generally occurs in larger quantities than *W. perfringens.* S. typhi is rarely isolated (Buttiaux, 1951; Gevaudan *et al.*, 1958).

The study of a Vi bacteriophage, the presence of which indicates pollution by *Salmonella typhi,* requires the use of standard strains rich in Vi antigen and hardly sensitive to bacteriophages of non-Vi type. Such strains may facilitate the isolation of specific phages by eliminating those to which they are not sensitive. The strains are chosen by means of two tests: (1) sensitivity of these strains to the action of various bacteriophages, and (2) study of new bacteriophages isolated with these strains (Guélin, 1950b).

The strain should be lysed exclusively by standard phages belonging to the same type. On the other hand, new phages, isolated by means of this strain, should in their turn not be active on bacteria other than those belonging to this particular species and type. The question could be raised, however, whether a strain which is sensitive exclusively to Vi-type phage would for any length of time maintain its specificity. Having a strain specific only for Vi-type phages does not exclude the possibility of some day seeing it become susceptible to bacteriophages of non-Vi type. For this reason the standard strain has to be constantly checked. Before isolating the various Vi phages, it is preferable to have a series of typhi-Vi strains with highly specific characteristics. It is easy to realize the importance of determining phage-types in bacterial species by establishing differences in their sensitivity to the bacteriophages. The method called "phage typing" makes it possible to collect a number of types for each region. This method, for which the principles are laid down by Craigie and Yen (1938), has been applied in France by Nicolle (see bibliography in Nicolle, 1957). In regard to the strains of *W. perfringens* which are not always of animal origin, Beerens and Delcourte (1958a, b) developed a test of obvious importance as it allowed the differentiation of fecal *W. perfringens* from the soil strains. This test is based upon the study of the survival of vegetative forms in a solution of 20% sodium chloride.

B. WATER-PHAGES OF DIFFERENT SIZES

The variation in the size of the bacteriophages is reflected in the dimensions of the plaques formed by these corpuscles; the diameter of the plaques increases in proportion to the diminishing phage size (Elford and Andrewes, 1932).

We had the opportunity to study *Salmonella* bacteriophages producing large or small plaques, isolated from various waters. While the former were specific, active exclusively on one species, the latter were polyvalent, often attacking numerous bacteria of the coli-typhi and dysenteric groups (Guélin, 1952a, 1955b; Leclerc, 1957). Thus those small plaques phages can sometimes regenerate in other strains than the typhic ones. The pollution of waters by *Salmonella* is certain only in the case of isolation of Vi large plaques phages. Small plaques phages have first to be tested as to their specificity (see Figs. 3 and 4).

The occurrence of large and small plaques phages does not seem to be related to certain geographical locations. They are found in various waters, as in the Seine and the Thames rivers, and the Mediterranean Sea. On the other hand, their distribution changes with the season, which indicates a possible effect of day length. The appearance of small plaques phages coincides with the lengthiest and sunniest days of the summer. Large plaques phages then become less and less numerous but reappear during the winter.

The varying sensitivity to light, exhibited by bacteriophages of various dimensions has been studied by Guélin (1942), Rouyer and Guélin (1942), and Wahl (1946). Their investigations were preceded by those of Wollman and Lacassagne (1940), who established the different resistance of large and small bacteriophages to X-ray.

Daylight seems to be to a great extent responsible for the disappearing of typhic large plaques phages (Guélin, 1955b). Studies on the photosensitivity of bacteriophages in open basins, containing 700 liters of pond water and placed in a park, confirmed the laboratory findings.

The extreme sensitivity to light of the large plaques phages perhaps offers an explanation of the intermittent occurrence of phages of different size in the Seine and the Thames rivers, and the Mediterranean Sea (observed during the years 1952–1953). During the short daylight season of the winter, the disappearance of large plaques phages is delayed. Their number prevents the isolation of other bacteriophages because the greater dimensions of their plaques masks the smaller ones. It is possible that the simultaneous presence of unequal quantities of bacteriophages of varying sizes in a growing culture inhibits the development of one type at the cost of another. The greater light intensity during the summer season is accompanied by a decline in quantity of large plaques phages. Their presence no longer interferes with the development of small plaques phages. The number increases in proportion to the disappearance of large-plaque bacteriophages. This is only a hypothesis to explain the seasonal variations which have been found in the distribution of Vi large and small plaques phages at the surface of polluted waters. The question remains whether the bacteriophages of various sizes differ in their photosensitivity. Our observations apply exclusively to water close to the surface. Buttiaux (1951) recommends a sampling of water for bacteriophagic work at a greater depth. It is possible that deeper water layers, less accessible to solar radiation, contain phages of different sizes during any season. In the summer at the Suresnes dam of the Seine the author demonstrated the presence of numerous large plaques phages at a

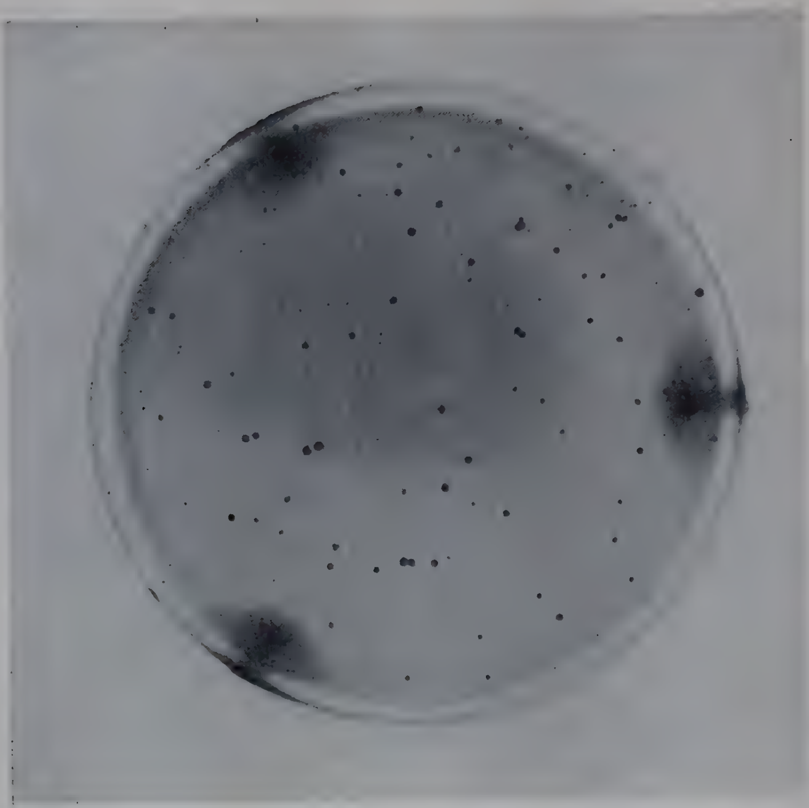

FIG. 3. Small plaques formed by the typhic bacteriophages on *Salmonella typhi* (after Nicolle *et al.*, 1953).

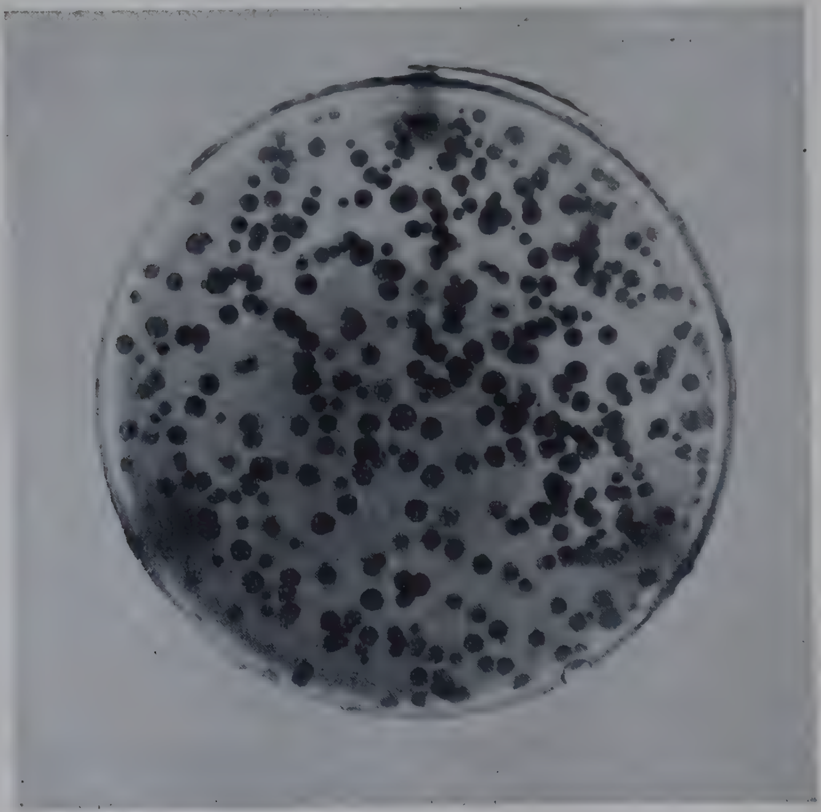

FIG. 4. Large plaques formed by typhic bacteriophages on *Salmonella typhi* (after Nicolle *et al.*, 1953).

depth of 3 meters, whereas the surface water contained only small plaques phages.

C. THE ROLE OF BACTERIOPHAGES IN THE PURIFICATION OF WATERS

It remains to examine the possible role of bacteriophages in the self-purification of waters. The destructive power of bacteriophages as regards bacteria attracted, from the very beginning, the attention of numerous workers. It has been suggested that the early observations of Hankin (1896) of the bactericidal effect of the waters of the Jumna and Ganges against cholera vibrios could possibly be ascribed to bacteriophages (Flu, 1923, 1941; Bilouet, 1926; Bujanowski, 1929; Beckwith and Rose, 1930; Guidice, 1931; Nyberg, 1931; Petrilli, 1940; Georgiades, 1952). On the contrary, Ware and Mellon (1956) never observed bacteriophagy, not even in sewage effluents.

It is, however, difficult to conceive the existence in a river of an important bacteriolysis identical to that observed in the laboratory. Such a phenomenon requires a multiplication of enteric bacteria to a degree difficult to attain in waters lacking sufficient nutritive constituents. Nevertheless, a minor quantity of organic material dissolved in the water may, under certain conditions, permit bacterial growth (Bigger, 1937) and a corresponding increase in bacteriophages (Guélin, 1945a, b). Thus, observation has been made of a multiplication of paradysenteric bacteria in a solution of peptone (1:70,000) invisible to the naked eye but attaining tenfold increases or more. In such a culture, the phages multiply and cause lysis of the bacteria (Guélin and Lépine, unpublished). It could, therefore, be expected that under favorable conditions a bacterial lysis by the phages might take place on a water surface. There is, however, little likelihood that such a lysis could in an efficient way aid the self-cleansing of waters, at least in nontropical waters.

The purificating role of bacteriophages can be shown further if the fact is taken into account that these phages are adsorbed on the surface of the pathogenic bacteria in the water. The introduction of such microorganisms, already contaminated by a phage capable of interfering with their multiplication, would imply a subsequent destruction of introduced bacteria.

Our observations with a microbial agent of gas gangrene confirm the active role of bacteriophages in the field of water hygiene, and also of *Welchia perfringens*, carrying phages in the water, were not destroyed even when a nonnutritive environment prevented multiplication. It was, however, sufficient to introduce these bacteria into a richer environment to obtain their destruction. They did not develop colonies at all or in smaller numbers than control colonies without phages (Guélin, 1950c). Guinea pigs injected with such bacteria showed no signs of sickness, while control animals, injected with bacteria not previously attacked by bacteriophages, showed all symptoms of the classic gas gangrene. The bacteria carrying phages were probably destroyed at the moment when they started to multiply in the muscle tissue of the guinea pigs (Guélin, 1955a).

The presence of enteric bacteriophages in natural waters may therefore indicate a contamination of these waters by the corresponding bacteria. It may also reveal the presence of pathogenic germs in the water, e.g. in the case of the typhus bacilli or *W. perfringens.* The research technique for bacteriophages is simple and rapid. Even small quantities of phages in waters diluted up to a million times are detectable. All these results permit considering the bacteriophagic method as complementary to the colimetric one. In the field of water sanitation the use of bacteriophages is not limited to the study of polluted waters. They indirectly participate in the self-purification of waters; a practical application of this discovery might be envisaged.

III. Enteric Bacteria and Bacteriophages in Fish

We have tried to establish a relationship between the bacteriological status of the digestive tract of fish and the sanitary conditions of the waters. Intestinal bacteria and bacteriophages in the viscera of 75 fish were investigated along with an identification of their occurrence in the corresponding waters. This study was carried out during the months of August and September at the Arago laboratory in the Mediterranean (Guélin, 1952b).

The fish were caught by dragnet or bownet in the immediate proximity of the coasts (Bay of Banyuls and that of Port-Vendres), or by trawling a few miles from the coast, at depths between 60 and 100 meters. Catching at a certain depth was necessary to obtain specimens which had not been in contact with coastal waters, and also to avoid taking fish coming from superficial layers of water, possibly contaminated accidentally by passing ships or in other ways.

Each sample was tested as to the presence of coliforms, of *W. perfringens,* and of bacteriophages, active on these microorganisms. The count of the total number of germs was established each time. In the water samples, the presence of enteric bacteriophages was determined. In order to isolate and to identify these bacteria, we applied the methods employed in the laboratory of Professor Buttiaux at the Pasteur Institute in Lille (Buttiaux, 1951, 1958; Buttiaux *et al.,* 1956). The search for bacteriophages was carried out by applying the technique developed in our laboratory.

Seventy-five specimens of fish were examined. They belonged to the following species: *Blennius palmicornis* Cuv. et Val., *Blennius ocellaris* L., *Crenilabrus roissali* Risso, *Gadus capelanus* Risso, *Gobius* sp., *Gobius capito* Cuv. et Val., *Gobius quadrimaculatus* Cuv. et Val., *Julius giofredi* Risso, *Julius vulgaris* Cuv. et Val., *Merluccius vulgaris* Flem., *Mullus barbatus* L., *Pagellus erythrinus* Cuv. et Val., *Serranus cabrilla* L., *Serranus hepatus* L., *Smaris maurii* Delav., *Smaris vulgaris, Trigla aspera* Vivi., *Trigla cuculus* Risso., *Trigla lineata* Will., *Zeus faber* L.

The fish samples can be classified into two groups: one comprising 30 samples collected from the high seas and 45 from the littoral zone.

In the viscera of fish caught in the high sea we never found bacteria belonging to the intestinal group such as *E. coli* or *W. perfringens,* nor *coli* or *perfringens* bacteriophages. In two cases we did isolate a germ, reducing sulfites. Presumably this may be ascribed to a secondary contamination. In the majority of cases, the agar and even the broth, both containing lactose, remained sterile after inoculation with the contents of the intestines. These facts do not indicate an absolute sterility of the viscera of the specimens taken in the high seas. A microscopic investigation of their intestinal contents always showed the presence of fine gram-negative rods and of gram-positive cocci. The isolation of these halophilic bacteria requires the use of special media and have been of no interest to us in our work, as it was aimed at a study of bacteria belonging to the Enterobacteriaceae.

The results obtained with fish from the coastal area gave a different picture. The inoculated plates exhibited an abundant development of aerobic and anaerobic germs up to a count of 10^6 per milliliter. The culture on the Vincent substrate was exuberant, sometimes with a production of indole. The lactose substrates often fermented with a production of gas. Numerous bacteria producing hydrogen sulfide, as well as proteolytic species, were found. Anaerobic germs producing hydrogen sulfide were found in 23 samples out of a total of 45. Prévot (1948) indicated that in addition to *Welchia perfringens,* 21 species of the *Clostridium* group are capable of reducing mineral sulfites. As a matter of fact, only 2 of the 23 colonies isolated belonged to *W. perfringens.* The rarity of this species explains the negative outcome of the search for *perfringens* bacteriophages. In 45 fish specimens from the littoral zone, *E. coli* was isolated in 8 cases, *E. intermedium* twice, *Aerobacter* 5 times, and *Proteus* and *B. paracoli* once each. Coli bacteriophages were found only in 3 cases.

So we find that in distant waters, which do not carry either coli-typhi bacteriophages or bacteriophages active on *W. perfringens,* fish do not contain enteric bacteria in their digestive tracts. On the other hand, in coastal waters where the bacteriophages of *Salmonella* and of *W. perfringens* are constantly isolated, the viscera of fish contain an abundant flora, in which, however, the enteric bacteria of man and those of the warm-blooded animals are not common. So the enteric bacteria do not seem to represent the normal flora of fish which confirms the findings of certain authors quoted above. The presence of enterobacteria in a fish may be explained by its being contaminated, and thus reflects a pollution of the waters which the fish has been frequenting.

The rarity of *E. coli* and of coliphages in contaminated fish from the littoral zone leads one to believe that these germs are not adapted to the digestive tract. Buttiaux had already expressed doubts as to the chances of survival of enteric bacteria of man in the viscera of fish.

Studies were, therefore, started with an experimental contamination of fish viscera. All these experiments were executed at the Laboratory for Marine Biology at Plymouth, England. The collected material was analyzed at the Pasteur Institute in Paris. In the course of these experiments, 61 samples of *Ctenolabrus rupestris,* of average size, were contaminated with either *E. coli* 16, or with coliphage 36. Previous examination of some specimens of *Ctenolabrus rupestris,* as well as of the waters used in these experiments, eliminated the possibility of the presence of *E. coli* and of coliphages other than the experimental contamination. The fish were then placed in clean water for observation.

According to the results, the contamination of fish by *E. coli* and by coliphages is not of long duration. Five hours after the contamination the bacteria and the bacteriophages were isolated from the viscera of the fish directly without any previous special handling. Twenty-four hours later, the isolation of the germs already required an incubation of the intestinal juice. On the sixth day after incubation, it was possible to identify *E. coli* in merely 60% and the phages in 80% of the cases. On the seventh day, no fish contained *E. coli* any longer. The bacteriophages disappeared between the eighth and twelfth day, although the water of the aquarium contained small quantities of them (Guélin, 1954).

These observations indicate the incapacity of *Escherichia coli* 16 and coliphage 36 to adapt themselves to the digestive tract of *Ctenolabrus rupestris.* It would be necessary to repeat these experiments with other species of fish and other enteric bacteria. The brief survival period of intestinal bacteria of man and warm-blooded animals in the fish digestive tract does, however, offer a basis for demonstrating the pollution in waters, where fish are caught.

An entirely different problem is whether such polluting microorganisms subsequently may influence the spoilage pattern of contaminated fish. Some observations of this nature are discussed in Chapters 15, 16 and 27.

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CHAPTER 13

Salmonella Problems in the Sea

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I. Introduction

Recent publications all prove the negative results of studies undertaken to find salmonellae and other enterobacteria of fecal contamination in marine fish caught in the open sea. Certain observations indicate, however, their presence in fish when they are marketed fresh or dispatched from the filleting or icing establishments.

Marine fish, nevertheless, seem to be rare agents for transmission of enteric bacteria, at least in countries with good sanitation standards. Edible oysters, mussels, and other shellfish are, on the other hand, very often infected by salmonellae, because the indispensable sanitary precautions are neglected in the cultivation areas. They are still frequently the origin of large epidemics of typhoid fever in some regions of the world.

For marine fish as well as for mollusks, contamination by pathogenic enterobacteria may be caused by a number of factors, being subject to argument still and in certain respects insufficiently studied. Nevertheless, they will be further analyzed below.

II. Self-cleansing of the Sea

The sea is the natural recipient of surface water from the land. Along the coasts, it also receives used water, sometimes without any previous cleansing treatment, either directly or via river mouths. Far away from shore, sea water may be polluted by fecal substances from birds or ships. Even though the former, for all practical purposes, constitute a negligible source of contamination, the latter may cause water surfaces to be temporarily highly contaminated. This has been observed when naval units pass an area. But aside from such exceptional circumstances, fecal pollution of the marine environment is almost exclusively a coastal phenomenon.

The purification of sea water containing salmonellae, sometimes in relatively large quantities, depends on factors different from those which intervene in other external environments. The self-cleansing may be due to special conditions, some of which are still insufficiently known. Two factors in particular are important:

The dilution of sea water through fresh water, in the form of discharge from rivers or sewage outlets, is no simple and predictable phenomenon. Because of the lower density and frequently higher temperature of the incoming fresh water, a thorough mixing is rendered difficult. This results in a greater degree of immobility of fresh water on the surface of the sea. Fortunately, other factors, such as prevalent wave movements, contribute to a greater mixing, especially when they are produced by winds hitting the surface.

The transportation of polluted water by surface currents, too, plays a role. The thin film of fresh water is removed by the tide and such currents. Subsurface currents have only a secondary influence, while those on the surface are predominant and almost exclusive agents in sea water without strong tidal movements. This phenomenon has been thoroughly analyzed by Moore (1954a).

So it is evident that an intimate mixing of sea water and polluted fresh water is difficult or takes place very slowly. Under these conditions, rather unfavorable for a cleansing action through dilution, the following factors are most essential in order to accomplish a reasonable purification of the water:

Oxidation is facilitated by waves and stream movements.

Sedimentation and absorption by marine sediments exert an influence on the rate of cleansing. Some authors consider the latter as playing an important role (Rubentschik *et al.*, 1936). However, the decrease in the number of microorganisms found after active sedimentation is only apparent. The microorganisms fixed to deep sedimented layers stay there only temporarily. They are not destroyed, and go into suspension, sometimes, through waves, winds, and currents.

The destruction of bacteria by protozoans and microscopic animals normally living in the sea or in the polluted water reaching the sea is another essential force. Stryszak (1949) suggests that these protozoans are the major agents for the destruction of salmonellae in a marine environment. Waksman and Hotchkiss (1937) remark that the multiplication of the protozoans, copepodes, and other minor marine animals is proportionate to the degree of destruction of bacteria in the zones studied.

Bacteriophages probably contribute little or not at all, in this case, toward the destruction of pathogenic bacteria. The bacteriophagic lysis requires, as a matter of fact, a temperature favorable for the multiplication of these germs: this condition is generally not present in the sea.

The salinity of the marine environment (35 per thousand, average), too, has little effect on microbial life.

Some authors seem to neglect the highly favorable influence of solar irradiation, which is not mentioned in the studies by Pearson (1956). According to Ruys, its importance in polluted waters was observed in the coastal zones of the Mediterranean.

Finally, everyone who has taken an interest in marine biology admits that sea water has a bactericidal effect on enterobacteria. As early as 1885, Nicati and Rietch, and somewhat later De Giaxa (1889), found that sea water sterilized by heat lost its inhibiting effect on *Vibrio comma* and *Salmonella typhi*. Krasilnikov (1938) showed that a simple treatment through a Seitz filter clearly decreased its aggressive action on terrestrial bacteria. Beard and Meadowcroft (1935) found the same phenomenon for *Escherichia coli* and S. *typhi*. The nature of this bactericidal power is still being discussed, but everybody admits its thermosensitivity, which was proved by Ketchum *et al.* (1949) and by Heim de Balsac *et al.* (1952). The latter authors suggest that the active agent is an antibiotic substance, but this has not yet been proved. For Vaccaro *et al.* (1950), it is due to marine bacteria producing substances which inhibit soil bacteria. Rosenfeld and ZoBell (1947) also remarked that nine species of marine bacteria isolated by them had obvious antagonistic properties to soil microorganisms, especially *E. coli*. Nusbaum and Garver (1955) disagree, having found inhibitory activity in sea water in samples almost deprived of marine bacteria and of phytoplankton.

Additional phenomena may interfere with this self-cleansing process, but they are without doubt of less importance.

III. Survival of Salmonellae and Other Enterobacteria in Sea Water

This question has been studied by numerous scientists as presented in a survey by Orlob (1956). Nevertheless, the data hitherto collected are still highly inadequate. It is indispensable to follow through with further investigations before giving any final opinion as to the risks of survival of these bacteria. A review will be made of observations on the survival of enterobacteria, whose presence was due to fecal contaminations of sea water as well as to the viability of salmonellae.

A. *Escherichia coli* AND COLIFORMS

The survival of these bacteria was specially studied *in vitro* which is largely responsible for the limited value of this research. It is actually impossible to compare conditions in bottled sea water, inoculated with microbes, to that of water in its natural environment, where it is subject to a multitude of varying influences, as wind, sun, currents, temperature, etc., which are completely or partially eliminated in the laboratory. On the other hand, there are notable differences in sensitivity between the bacteria present in sewage water and the same species cultivated in an artificial environment, as was the case in these *in vitro* experiments. Finally, it should be pointed out—as stated by Brisou (1954)—that the amount of bacteria inoculated into sea water is often much too high and in any case far in excess of the numbers found in naturally polluted waters. Be this as it may, all research workers note a more or less rapid disappearance of bacteria when in contact with sea water. *E. coli* and the coliforms are the least resistant to destruction.

For Weston and Edwards (1939) this happens within 24 hr. In the experiments carried out at Santa Monica (California Department of Public Health, 1943) a degree of survival from 1 to 2.5% of the coliforms after 24 hr. was established. Clifton (1948) gives a mortality rate of 98.5% within 5 days. It is 97% in 48 hr. in the studies by Moore (1954b), and ZoBell (1936) previously obtained practically identical results. Nusbaum and Garver (1955) register a decrease in the number of coliforms after a lag period, shorter in sea water, the sampling of which had taken place in spring. Temperature has its influence: the number decreases from the third day at 30°, but remains unchanged during 9 days at 5°. Gevaudan and Tamalet (1956) found a complete disappearance of *E. coli* in 24 to 48 hr. when they were inoculated in low concentrations into the water of the Mediterranean.

In addition to these experimental studies, it is useful to examine the phenomena of purification taking place around the outflows for sewage water. Old studies show in general a rapid diminution of coliforms and of *E. coli* with increasing distance from the point of outflow. These investigations were surveyed by Brisou (1954). More recently, Gevaudan and Tamalet (1956) show that the area into which these bacteria spread around the outflow has a maximum range of 500 meters in the Mediterranean. Actually, all these statements, both the older ones and those of more recent dates, were made without taking into consideration currents in the surface water to which attention has been drawn by the Pasteur Institute. They play a paramount role in the spreading of polluted waters across the surface of the sea. This difficulty was avoided by determining in advance the presence and direction of such drifting water. On the other hand, the samples used were taken at depths of 50 cm. in layers definitely known to contain the effluents. Samples of sewage water taken from the mouth of the Rance (English Channel) and on sandy beaches on the coast of the North Sea were studied in this way. The results of these studies, which took place during the warm months (from the end of May until the end of July), are presented in Table I. It shows that complete purification is not achieved within a range of 400 meters in the North Sea, and in the mouth of the Rance it was furthermore influenced directly by the tide. In the latter case, it is necessary to go 1,000 meters from the outflow to find a complete disappearance of coliforms and of *E. coli*. Our results under the strict conditions in which they were obtained prove that in the North Sea and the Atlantic the purification of contaminated water is less rapid than in the Mediterranean. They come close to the conclusions of Aglitskii and Khait (1952), who sometimes observed contamination of sea water at a distance of 3,000 meters from the point of outflow of sewage.

TABLE I

FECAL ORGANISMS FOUND IN SEA WATER AT VARYING DISTANCES FROM THE POINT OF SEWAGE OUTFLOW

Place of catch (meters from sewage outflow)	Coliforms[a]	*E. coli*[a]	*Streptococcus* D.[a]	Spores of *C. perfringens*[a]	"Fecal" bacteriophages	*Salmonella*
North Sea						
10	1,000	1,000	1,000	34	+ in 1 ml.	+
200	100	100	40	16	+ in 1 ml.	0
400	100	100	40	23	+ in 5 ml.	0
Mouth of the Rance (two sewage outlets)						
10	10,000	10,000	1,000	260	+ in 0.1 ml.	0
200	100	100	100	0	+ in 5 ml.	0
400	100	100	100	33	+ in 5 ml.	0
10	100,000	100,000	1,000	400	+ in 0.01 ml.	0
200	10,000	10,000	1,000	140	+ in 0.1 ml.	0
400	10,000	10,000	25	13	+ in 1 ml.	0
800	100	100	0	46	+ in 50 ml.	0
1,000	0	0	0	0	+ in 50 ml.	0

[a] Per 100 ml.

B. *Salmonella*

It is generally considered that salmonellae are no longer found where *E. coli* and coliforms are controlled or have disappeared. This reasoning results from the neglect of two basic principles during experimental studies:

1. The number of *E. coli* and coliforms in the feces is much greater than that of salmonellae. The law of relationship thus indicates that if the former are absent, the second are absent *a fortiori*. The observations by Thomson (1955) should be brought to attention. He found 50×10^6 salmonellae per gram of fecal substance from sick persons as well as from healthy carriers. It should also be kept in mind that the coliforms are present in small number in the normal intestinal flora of certain animals such as the pig, while salmonellae can occur there in great numbers (70×10^7, according to the Pasteur Institute studies);
2. The resistance of salmonellae to physical and chemical agents is comparable to that of the escherichiae but nothing proves that this is also the case in sea water.

In experimental investigations on the inoculation of *salmonella* cultures into sea water in bottles, the duration of their survival is proportionate to the amount of inoculate.

Gevaudan *et al.* (1957) found that S. *typhi* at a dosage of 100,000 per milliliter survived under these conditions for 3 days; with a dose of 25,000, none survived more than 15 min. in the water from the Mediterranean Sea. Sherwood (1952a) observed the disappearance of S. *paratyphi* B (5,450/ml.) in 24 hr. and that of S. *typhi* (41,800/ml.) in less than one week. In collodion sacs immersed in the bay of San Francisco, Beard and Meadowcroft (1935) with an inoculation of 300 million S. *typhi* per milliliter found viable cells after 14 and 34 days. Buttiaux and Leurs (1953) in water from the North Sea taken out at sea found destruction of less than 50% in 44 hr. for S. *typhi*, S. *paratyphi* B, S. *enteritidis*, and S. *typhimurium* (200 to 1,800/ml.). These results are much less optimistic than those of Gevaudan and Tamalet and seem to be confirmed by the findings of Lafontaine *et al.* (1956) utilizing comparable types of water; 50% of *E. coli* survived after 48 hr. in this water at 20°C. (68°F.) and 37°C. (98.6°F.).

It has been possible to investigate salmonellae in the sea. Through sampling at Santa Monica, S. *paratyphi* B was isolated in 6 out of 10 cases. Steiniger (1951) gave an important contribution to the study of this problem. He described a special abundance of S. *paratyphi* B in the waters of the port of Husum (Germany); the calculations prove that these bacteria could multiply, availing themselves of abundant organic substances in the surrounding water. More recently Steiniger (1956) found different species of *Salmonella* in the waters of the port of Barcelona and its surroundings. *S. paratyphi* B, var. *java, S. bareilly, S. typhimurium* were all isolated in this area (2–8/ml.). In sea water receiving nontreated sewage water, Buttiaux and Leurs (1953), found *S. montevideo* in numbers of 10 to 20/ml., and their counts did not diminish noticeably when the water was maintained at +4°C. (39.3°F.) in the bottles.

These publications show that it is not exceptional to find viable salmonellae in sea water contaminated by polluted water. At the present, however, it is impossible to maintain that these bacteria may be encountered all along the coastal area, even outside the polluted zones. These conclusions naturally are essential in explaining the origin of salmonellae occasionally found in edible fish or shellfish.

IV. Behavior of Salmonellae and Other Enterobacteria Within the Body of Marine Fish

One may safely disregard papers published between 1899 and 1909. It is hardly possible to interpret them in terms of the concepts now prevailing in bacteriology. Besides, they were reviewed by Guélin in 1952.

Bruns stated in 1909 that body organs and flesh of healthy fresh fish are sterile at the moment of their catch. Later, other authors have confirmed that fish never contain coliforms when caught in the open sea. Nor is there any evidence which allows the conclusion that pathogenic enterobacteria may be encountered there (Shewan and Liston, 1955). On the other hand, everybody recognizes that fish may become infected through their intake of food when staying in sea water contaminated by sewage water or polluted rivers. This rule applies also to fresh-water fish. Floyd and Jones (1954) found *Salmonella* and *Shigella* in 11% of the fish in the Nile. Marine fish react the same way. Griffiths (1937) isolated coliforms exclusively in specimens which had been in contact with contaminated water. Venkataraman and Sreenivasan (1954) confirmed this fact, but they found practically no coliforms in fish caught 15 kilometers off the coasts of Tellechery (Malabar on the west coast of India). Van den Broek (1948) proved the presence of salmonellae in the viscera of eel kept in the polluted waters of a port. Gulasekharam *et al.* (1956) found numerous salmonellae in ocean fish available on the markets of Colombo (capital of Ceylon). The coastal waters there are abundantly polluted by sewage.

But in all these cases of contamination when the fish is staying in an environment contaminated by enterobacteria, these bacteria are readily eliminated as soon as it is returned to noncontaminated water. Consequently it behaves like oysters, mussels, and other shellfish, whose self-cleansing is reliable and rapid when they are placed in clean water. Thus Gibbons (1934b) noted the almost permanent absence of bacteria in the intestines of "fasting" fish. He is of the opinion that escherichieae do not normally occur in the digestive system of marine fish. Markoff (1939–1940) thinks that fish more or less rapidly get rid of these bacteria, and particularly enterobacteria, which they may, however, carry temporarily. ZoBell (1946) is of the same opinion, but he also notes that *B. aerogenes* is found more often in fish than *E. coli.* This species can subsist a long time in fish once they have invaded them. Simultaneously studying enterobacteria and bacteriophages of coli and salmonellae, Guélin (1952) came to the following conclusion regarding fish of the Mediterranean. On the whole, when water did not contain the bacteriophages in question, the intestines of the fish were in most cases free from the corresponding enterobacteria.

The studies quoted above all lack experimental tests. In fact, it is impossible to know if fish caught some 10 miles from the coast did not previously sojourn in polluted zones adjacent to or at the coast. Guélin (1954) has supplied information of great interest obtained in a laboratory but under conditions close to those of nature, thanks to installations at the Department of Marine Biology at Plymouth. Sixty-one specimens of *Ctenolabrus rupestris* were artificially contaminated by *E. coli.* These bacteria disappeared from the intestines of the fish after 7 days in non-infected sea water. These observations are more closely analyzed in Chapter 12. Unfortunately, no similar research has been carried out for salmonellae. They presumably react in the same way, as they are not pathogenic to the fish. As far as our knowledge goes, salmonellae have never been found to cause diseases in aquatic animals.

V. Salmonellosis Caused by Fish Intake

As just clarified, fish caught in distant waters, i.e., those dominating the fish trade, may be considered free from pathogenic enterobacteria. At the moment of their catch no microorganisms have been found which point to fecal contaminations, such as *E. coli* or other coliforms, streptococci D, fecal bacteriophages, etc. The sanitary aspect is completely different when analyzed at the point of sale to the customer or on arrival at a processing plant. Spencer and Georgala (1958) isolated coliforms in 92%, 78%, and 68% respectively, of the cases during three series of examinations carried out in Scotland. They appeared during the handling or in the operation of transporting or processing. The detrimental effects of fecal contamination in the course of preparing frozen fish was pointed out by Larkin *et al.* (1956). The most frequent causes for these extra-marine contaminations may be summarized in the following way:

1. One source may be the ice used in the holds of the ship or in boxes ashore, if it is manufactured from polluted water. Hompesh (1953) attributes an epidemic of typhoid fever in Dortmund to this factor.

2. Lack of cleanliness in the hold is another pathway for such contamination.

3. The boxes or baskets used for transportation of fish from the ship to the market are often charged with bacteria. They are particularly numerous in the film of organic substances which covers the interior surface owing to inadequate washing and disinfection. The Pasteur Institute studies gave the following figures: aerobic bacteria: 2.9 million per gram; *E. coli:* 100,000 per gram; fecal streptococci: 20,000 per gram; sulfite-reducing *Clostridia* (spores): 800 to 1,000 per gram. These bacterial contaminations are particularly important in wooden or wickerwork crates; they are less important in metal boxes, the cleaning and disinfection of which are much easier. Gianelli and Braccio (1956) point out that the degree of contamination decreases from 10 million to 1 in wood as compared to aluminum.

4. The manual worker as a carrier of microorganisms plays, as in other food industries, a major part in this contamination. Observations by Olitzky *et al.* (1956) confirm this: smoked fish caused 3 institutional food poisonings; *Salmonella newport* was isolated in the product and in one of the seventy employees of the processing plant; he was in charge of packing the smoked fish.

5. Poor sanitary conditions in and around the processing facilities may also take the blame. Badiali *et al.* (1957) isolated *S. paratyphi* B in tuna; the place of unloading was infected by dogs, cats, and rats.

The presence of salmonellae as a result of such unsatisfactory conditions during handling, transport, and processing is particularly prevalent in fish meals used for animal feeding. In Germany, Rohde and Bischoff (1956) isolated salmonellae 43 times in 270 samples from imported meal. Clarenburg (1958) reports similar findings in the Netherlands. These meals cause numerous infections, visible or invisible, in such animals as pigs and poultry, to which they are fed. The *Salmonella* types found in men in Hamburg during recent years show a surprising resemblance to those encountered in fish meal sold in the same region. Handloser (1956), during a large epidemic of human salmonellosis which raged in Brackwede (Germany) following consumption of pork sausage, was of the opinion that the meat utilized in their manufacture came from animals fed with contaminated fish meal.

These observations indicate that salt-water fish, justly considered one of the wholesome and sanitary foods at the time they are caught, no longer possess this high degree of cleanliness when they reach the consumer (Hobbs, 1954). It would be a mistake to rely on the use of antibiotics to avoid these hazards; it is essential above all to improve the sanitary conditions in handling, transporting, and processing.

VI. Salmonellae in Edible Shellfish

Salt-water fish that have been contaminated in coastal waters have great opportunities to eliminate the enterobacteria they have ingested during their stay in clean offshore waters. This problem is different for oysters and clams, which for their growth require a mixture of salt water and fresh water; the statements about optimum salinity for growth vary with individual research workers—from 8,750 to 30,800 p.p.m. but should never reach 35,000 p.p.m., the normal chloride concentration of sea water. The mussel and oyster beds are invariably located along the coasts and especially in river mouths with tidal water movements. This provides the shellfish with a sufficient amount of fresh water but also increases the risks of dangerous contamination. In addition, mollusks of the group Lamellibranchia filter water, which they absorb, and retain a substantial part of the bacteria present in the water. According to Viallanes (1892), an oyster 18 months old filters 5 liters of water in 24 hr.; during the same time, a mussel extracts 1,768 g. of silt from the water if the original content thereof is 0.0546 g. per liter. Gevaudan and Gay (1958) found the following facts: in water containing 2,400/ml. S. *typhi*, only 120/ml. bacteria are found after 24 hr.; mussels immersed in this same water show, on the other hand, a count of 400 to 800/ml. after the same period. If a renewed contamination of the water is carried out with water containing a concentration of S. *typhi* of 3,200/ml., the mussels after 24 more hr. show counts of 800 to 1,600/ml. but the surrounding water only contains 170/ml. This concentrating action by the mollusks renders them hazardous to the consumer, if eaten raw and without previous purification. The contamination of sea water through fresh water or polluted water containing salmonellae should, therefore, be avoided at all costs in the zones employed for the cultivation of edible shellfish as well as in the natural locations for their development. Keeping in mind the studies discussed in Section III, B, it is obvious that salmonellae survive in marine environments during a sufficient length of time to be ingested in a fully vital stage by the mollusks. The latter, on the other hand, being completely immobile, cannot benefit from any self-cleansing of water; the waters in which they live may, in fact, be repeatedly polluted. Finally, those enterobacteria that are absorbed may survive for a long time after the catch. Hunter and Harrison (1928), in surveying the literature, found that S. *typhi* remains alive during transportation to the consumer. Kelly and Arcisz (1954) studied experimentally the behavior of S. *paratyphi* B in the flesh of oysters and clams and arrived at the same conclusion.

These phenomena explain the frequency of salmonellosis provoked by oysters, mussels, and other shellfish. They have all been, and still frequently are, the cause of epidemics of typhoid fever, sometimes very serious ones. The list of observations in France of these incidents is too long to be presented here (Brisou, 1955). It may suffice to recall the United States epidemics in Chicago, New York, and Washington in 1924–1925. They were studied by Lumsden *et al.* (1925); 1,500 cases were reported, with 150 deaths.

It is difficult in practice, despite several controls, to avoid entirely the pollution of waters surrounding oyster and clam beds. Very often, desirable conditions are not reached (Buttiaux *et al.*, 1955), or, as was rightly pointed out by Arcisz and Kelly (1955), the growing beds for many clams remain rare in zones of clean water due to the fact that greater yields are obtained in polluted areas. It seems, thus, to be a safer way for public health authorities to plan for a systematic cleaning of mollusks before they are put on the market. The methods to be applied are now well-known, extensively tested in practice, and proved to be reliable. They are based on the following principle: mollusks contaminated with enterobacteria free themselves from these within 24 to 48 hr. when they are placed in water of sufficient salinity and devoid of bacteria. Erdman and Tennant (1956) found that this kind of self-cleansing takes place in clams immersed into naturally clean water. In practice, water chemically sterilized, especially by chlorine, is very often used. Dodgson (1928) described the operations and precautions necessary to obtain satisfactory results. Allen *et al.* (1950) recommended a simpler system of closed circulation. Sherwood (1952b) insists that it is indispensable to dechlorinate the water prior to putting it into contact with the mollusks; in the presence of any traces of free chlorine, the latter, it is claimed, are less active and do not pump through their bodies sufficient amounts of water. The ensuing self-cleansing consequently proceeds too slowly. Ozone, like chlorine, is said to have an irritating effect, disturbing the normal rate of the cleansing operations. Chlorinated water subsequently dechlorinated is largely used for oysters in England, e.g., at Conway. Comparable installations are operated for clams in Massachusetts. It should be kept in mind, however, that a self-cleansing of mollusks achieved under these conditions is never complete; some *E. coli* and salmonellae always subsist at the end of 48 hr. of treatment. Their final number depends upon the degree of initial contamination. So it is indispensable to avoid fecal contamination in the grounds of cultivation, if safe mollusks are to be obtained. All sanitarians agree on this point, and numerous countries have prescribed appropriate measures. In a conference arranged by the World Health Organization (1958), satisfactory methods of treatment were recommended. It was also suggested that all sewage flowing directly into the sea in the vicinity of mollusk beds be chlorine-treated.

VII. Salmonellae in Fish and Shellfish

The sanitary standard of these products is generally defined by counting the coliforms or, more specifically, the *E. coli* and fecal streptococci. The search for sulfite-reducing clostridia is of less value, as these bacteria are normally present in marine silt. Investigations of this nature constitute the basis for standards prescribed in numerous countries. Only on rare occasions are the salmonellae included in such a routine control. Such a determination does, however, present very minor difficulties and should, in our opinion, be executed far more commonly, particularly in the case of edible mollusks. The procedure to follow is described below.

A. Mollusks

The enterobacteria are particularly concentrated in the intestines and seem to be less abundant in the liquid between the valves. This kind of distribution is not uniform, however, and an examination of this latter liquid should not be neglected.

The meat and the liquid between the valves of 10 oysters, 20 mussels, or 30 clams are collected in the most aseptic way possible, in a sterile glass container. The entire sample is minced in a mixer. Inoculations are made from this mixture into beakers containing at least 100 ml., using two substrates favorable to the growth of salmonellae. We use simultaneously either two of the following three: selenite or sodium tetrathionate (Muller-Kauffman) or of potassium tetrathionate (Preuss). After 24 and then 48 hr. of incubation at 37°C., a small quantity of the two substrates is transferred to selective plates for isolation on S.S.-agar, desoxycholate-citrate-lactose-agar or bismuth-sulfite-agar. The latter should be reserved particularly for the search of S. *typhi.* Suspected colonies are isolated and identified after suitable incubation at 37°C., following standard procedure. It should not be overlooked that marine mollusks often carry achromobacteria, which sometimes grow on substrates recommended for the identification of salmonellae. Like these latter, they give noncolored colonies (lactose —) which may resemble those salmonellae that do not produce H_2S.

B. Fish

It appears important to direct research not only toward identifying the presence of salmonellae but also toward tracing their origin. These bacteria may derive from polluted waters where the fish have stayed. They are then present in their intestines. They may reach the fish by contamination in handling them subsequent to death. In this case the salmonellae cover the external surfaces of the fish body. The following procedure is recommended: fragments of the skin taken out with a scalpel are cut with scissors and placed in the two media described above; the viscera are removed completely; they are minced and inoculated in the same media. The subsequent operations are identical to those described above for mollusks.

By using the preceding methods, we have encountered salmonellae seven times in oysters, mussels, or clams caught in coastal water receiving untreated sewage effluents. We have never succeeded in finding these in fresh fish on the retail market. The recommended techniques, however, are satisfactory because our investigations have been positive in establishing the presence of salmonellae in fish submitted to experimental contaminations in aquaria.

VIII. Conclusions

This survey of our present knowledge regarding the *Salmonella* problem in marine environments has brought forth evidence supporting the following conclusions:

Salmonellae are spontaneously inhibited in their growth in sea water. Their complete disappearance, however, is delayed for a protracted period of time. Salmonellae carried into the sea by an outflow of untreated sewage effluents may easily contaminate mollusks and fish in adjacent waters.

Fish do not attach these bacteria to their body nor bind them when ingested. In this latter case, they free themselves of such salmonellae rather rapidly when reaching clean water. No observations of lesions or diseases in fish caused by salmonellae have been published up to the present time. For all practical purposes, fish caught off the coasts may be considered free from pathogenic enterobacteria. On the contrary, those caught in polluted littoral zones may be contaminated by such bacteria. Most salmonellae on fish are procured in the handling, transporting, or processing operations when these are carried out under inadequate sanitary conditions.

Edible mollusks concentrate salmonellae in their bodies. Requiring for their subsistence a mixture of sea water and fresh water, such mollusks are readily infected when sewage effluents are not strictly controlled in coastal areas where they grew. Shellfish have in the past caused and still give rise in some countries to epidemics of typhoid fever. Mollusks should be subject to a systematic constant control. As a precaution all mollusks should be submitted to a cleaning operation in tanks prior to marketing. In the end the sanitary quality depends upon the hygienic conditions in the grounds for cultivation and the sanitary standards of the water.

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CHAPTER 14

Biotoxications, Allergies, and Other Disorders

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I. Classification of Disorders Due to Consumption of Fisheries Products

From a medical viewpoint, the subject of disorders caused by eating fisheries products has been a complex, confused jumble of jargon. This has often resulted in erroneous diagnoses and a general misunderstanding of the problem at large. What are these disorders? How are they related to each other, if at all?

There are five general categories into which most illnesses caused by the eating of aquatic organisms can be classed. This classification purposely does not include contamination by radioactive substances since this topic is discussed in Chapter 18 of this volume.

A. Bacterial Food Poisonings

In this particular category are classed intoxications caused by eating aquatic organisms that have been contaminated by bacteria or their toxic products. In order to produce an intoxication, the food item must have served as a medium upon which causative bacteria were able to grow. According to this strict definition of the term, only those entities are included in which toxic products actually are formed in the food prior to eating. Typical of this category are botulism and staphylococcus food poisoning. Certain other types of infections are frequently listed in this same group but should more correctly be termed food-borne infections (see Section B), since the symptoms produced are due to the ingestion of living bacteria rather than their toxic products. Examples of the latter type of poisoning are those caused by salmonellas and *Staphylococcus faecalis.*

There are also some minor types of bacterial food poisonings which are of a more questionable nature. A distinctive characteristic of food poisoning is the sudden illness following the ingestion of a specific meal and involving a definite food item. With the exception of botulism, a gastrointestinal upset is a characteristic feature. It should be noted that putrefaction does not necessarily result in the production of toxic products. Putrid meat, as well as fish, is eaten in many parts of the world without ill effects. The subject of bacterial food poisoning through fish is analyzed in quite some detail in Chapter 11 of this volume. Reference may also be made to Meyer (1953) and Dack (1956).

B. FOOD-BORNE INFECTIONS

In this instance the food merely serves as a vehicle for the transmission of the disease agent. Theoretically, a wide variety of bacterial organisms can be conveyed in this matter. Some of the better-known diseases in which aquatic organisms have been involved are typhoid fever (*Salmonella typhosa*), paratyphoid fever (*Salmonella* spp.), bacillary dysentery (*Shigella* spp.), cholera (*Vibrio comma*), and other salmonella infections. Sanitary conditions, i.e., control of sewage pollution, methods of food preservation, and cooking, are significant factors in averting these diseases. Food-borne infections differ from food poisonings in that in the former group a lag in the appearance of disease symptoms occurs due to the incubation period required by the bacterial contaminants for building up in the body.

C. VECTORS OF PARASITIC DISEASES

Certain species of fresh-water fishes may serve as intermediate hosts in the transmission of such helminths affecting man as *Diphyllobothrium latum, Clonorchis sinensis, Opisthorchis felineus, O. viverini, Heterophyes heterophyes,* and *Metagonimus yokagawai.* Fresh-water crabs and crayfish are known to transmit the lung fluke, *Paragonimus westermani.* Infections result from the ingestion of improperly cooked, raw, frozen, dried, or pickled fish (Mackie *et al.*, 1955).

D. ALLERGIES PRODUCED BY FISH AND SHELLFISH

The exact nature of the physiological mechanisms involved in allergic reactions is not entirely understood. In the case of food allergy, certain foods serve as exciting agents, termed allergens or antigens. These are specific substances that stimulate the production of correspondingly specific antibodies in a sensitive organism. Antibodies are of two general types, those which are free and circulating in the blood stream, and those which are attached to tissue cells. The latter are termed sessile antibodies. It is the interaction of the antigen with the sessile antibodies that produces symptoms in the sensitive individual. Allergic individuals are believed to have inherited a predisposition or capacity to become sensitized. Thus, there may be produced a high degree of sensitivity in the individual, resulting in a severe reaction to the allergen or antigen. It is commonly believed that there is a release of histamine in the damaged cell. However, other substances also are believed to be involved. An individual is generally sensitive to more than one allergen. Fish and shellfish are known to serve as powerful allergens which in some persons may produce almost explosive reactions. The most common symptoms produced by fish and shellfish are urticaria, angioneurotic edema, gastrointestinal disturbances, and migraine. Less common manifestations are asthma and coryza.

Group reactions to aquatic organisms are common. If a person is sensitive to one species of a phylogenetic group, he will probably be sensitive to all other members of the same general group. Hypersensitivity to all kinds of fish, however, is considered rare (Urbach and Gottlieb, 1946). Usually it is confined to one or related species. Wenderoth and Beneke (1956) report on three independent allergenic groupings of fish: (1) herring-sprat; (2) hake-cod; (3) plaice-sole. It was, however, formerly considered that if someone was allergic to a bone fish, such as cod, he was most likely to react also to trout, carp, herring, sardine, etc. A person sensitive to finned fish is not necessarily bothered by mollusks or crustaceans. Extreme cases of specificity have been reported. DeBesche (1937) noted a patient reacting only to Norwegian brisling sardines. On the other hand, minute traces of fish proteins, such as fish skin used for the clearing of coffee in Norway and France (Urbach and Gottlieb, 1946, p. 306), may serve as allergens. Wenderoth (1956) established a high degree of specificity. Cases do occur, however, in which an individual is sensitive to all types of seafood. People react rather frequently to sardine and salmon; less so to cod and halibut. Positive reactions have been reported, among others, for mackerel, tuna, and sole. Although fish and shellfish frequently act as powerful allergens, they are not essentially different from most other foods in this regard. Wheat, eggs, milk, chocolate, tomatoes, legumes, and pork are common offenders. For further discussion on the subject of food allergy the reader is referred to textbooks such as those by Urbach and Gottlieb (1946) and Vaughan and Black (1954) and a recent comprehensive review by Withers and Hale (1956).

E. Biotoxications

Included within this category are those disorders resulting from ingestion of a poisonous substance, a biotoxin present in the body of an otherwise edible aquatic plant or animal. Such compounds are derived from plants or animals, presumably as a result of metabolic activities. The precursors of these biotoxins, or in some instances the toxic substance itself, are believed to be derived directly through the food chain of the organism. With the single exception of scombroid poisoning (see p. 533) the degree of freshness or state of preservation of the organism has no bearing upon the production of the poison. Bacterial food poisoning, radioactive contamination, presence of parasites, and allergy are unrelated to the problem of biotoxications.

A characteristic feature of biotoxins is their apparent sporadic appearance in nature. There is no experimental evidence to indicate that so-called "poisonous species" are poisonous all the time and in every locality.[1] Whether toxic sessile marine plants and dinoflagellates are exceptions to the foregoing statement is not known for certain. However, sporadicity is certainly characteristic of many invertebrate and vertebrate poisons.

The few poisons that are reported to occur in fresh-water fishes, such as cyclostome and barbel poison, have not been studied to any extent. Unfortunately, only five marine animal poisons, viz., paralytic shellfish poison, puffer poison, murexine, holothurin, and saurine, have been subjected to critical chemical and pharmacological evaluation. Information on sessile marine plant phytotoxins is exceedingly meager (Schwimmer and Schwimmer, 1955; Dawson *et al.*, 1955; Habekost *et al.*, 1955). Considerably more is known about the geographical and phylogenetic distribution of biotoxins on the basis of clinical and epidemiological reports. Although it is recognized that clinical observations are a poor substitute for basic chemical and pharmacological studies, they are, nevertheless, revealing and do provide some insight as to the occurrence of these poisons in nature. Much of the more pertinent general literature has been reviewed elsewhere by the author (Halstead, 1956).

On the basis of the scanty information available to date, it appears that most biotoxins are water-soluble substances. They are generally resistant to ordinary cooking procedures. Those that have been studied to any great extent have been found to be small-sized molecules. Many biotoxins are similar in the clinical manifestations they produce, but there is some evidence that they are chemically distinct and probably vary somewhat in their mechanism of action. The chemical literature on marine biotoxins has been reviewed by Courville *et al.* (1958).

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[1] The term "poisonous," as presently used, is restricted to oral poisons, and should be differentiated from such parenteral toxins as venoms, which are an entirely different matter (see Section II, A, 2, a).

1. *Distribution of Biotoxins*

Biotoxins can be divided into two major biological groups: *phytotoxins* and *zootoxins*. Phytotoxins are those which occur in plants. Any of the alkaloids might be cited as examples. Zootoxins are those which occur in animals. Zootoxins may be further subdivided into two general categories: *parenteral* and *oral* toxins.

Parenteral toxins, i.e., animal venoms, are poisons introduced into the victim by means of a stinging or biting device. Animal venoms are to be found in numerous animal groups such as coelenterates, annelids, echinoderms, arthropods, fish, reptiles, and mammals. In fish, the venomous stings are generally situated on the dorsal fin, gill covers, or other fin spines. Venomous fish carrying specific poisons, termed ichthyoacanthotoxins, secreted by special venom glands, occur in most seas of the world. However, few food fishes are venomous, and in those species that are, their venomous properties have no adverse effects upon the edibility of the flesh, although their venomous stings may constitute a hazardous deterrent to their commercial use. The weever, *Trachinus draco,* which is an extremely venomous species, is usually processed in commercial filleting plants where the fillets are cut from the fish for the fresh-fish markets along the Atlantic coast of Europe. Many of the catfishes are venomous, but in most instances are not poisonous to eat. See Fish and Cobb (1954) and Halstead (1959) for further information on venomous fishes.

Oral toxins are poisons which are ingested. From the viewpoint of aquatic resources and food economy, there are two groups of primary importance—poisonous mollusks and fishes. However, it should be pointed out that oral zootoxins are widely distributed throughout the entire animal kingdom.

2. *Poisonous Mollusks*

There are two currently recognized main types of intoxications resulting from the eating of mollusks, namely, (1) paralytic shellfish poisoning, and (2) venerupin poisoning. There is a third type, termed cephalopod poisoning, which appears to be due to a pathogenic microorganism, but thus far all microbiological analyses have failed to reveal the etiological agent. There has recently appeared a fourth type of shellfish intoxication in Japan, termed Minamata disease, which is believed to be caused by a contaminating metallic compound of some type.

a. Paralytic Shellfish Poisoning

This disease has been recognized on the American continent since at least 1793, when it was first reported from Vancouver Island. Since then, numerous other cases have been described from the west coast of North America ranging from Alaska to the Gulf of California (Meyer, 1953). Medcof *et al.* (1947), Needler (1949), and Tennant *et al.* (1955) have cited a series of outbreaks along the east coast of Canada. More than a hundred cases of shellfish poisoning have been known to occur in South Africa, New Zealand, Belgium, Germany, France, England, and Ireland (Meyer *et al.*, 1928; Koch, 1940, Sapeika, 1948; von Bonde, 1948).

For many years, the primary cause of paralytic shellfish poisoning was unknown. It has now been demonstrated that the poison is derived from toxic dinoflagellates ingested by shellfish, which in turn are eaten by man (Sommer and Meyer, 1937; Koch, 1939; Needler, 1949). The dinoflagellate species *Gonyaulax catenella, G. tamarensis,* and *Pyrodinum phoneus* have been definitely incriminated, and still other species are suspected of serving as primary sources of the poison.

Some of the species of shellfish more commonly involved in human intoxications are the following:

California mussel (*Mytilus californianus*)
Common (black) mussel (*Mytilus edulis*)
Soft-shell clam (*Mya arenaria*)
Smooth Washington clam [syn. (Alaska) butterclams] (*Saxidomus giganteus* syn. *S. nuttali*)
Razor clams (*Siligua patula*)
White mussel (*Donax serra*)
Northern horse mussel (*Volsella modiolus*)
Solid surf clam (*Spisula solidissima*)
Atlantic jacknife clam (*Ensis directus*)
Sea scallop (*Pecten grandis*)
Common cockle (*Cardium edule*)
Edible oyster (*Ostrea edulis*)
Atlantic deep-sea scallop (*Placopecten magellanicus*)

A comprehensive review of most aspects of paralytic shellfish poisoning is by McFarren *et al.* (1957).

(1) *Clinical Characteristics*

The initial symptoms consist of a tingling or burning sensation of the lips, gums, tongue, and face, which gradually progress to the neck, arms, fingertips, legs, and toes. The paresthesias later change to a sensation of numbness. Voluntary movements become progressively worse. Other symptoms consist of weakness, dizziness, malaise, prostration, headache, salivation, incoherence of speech, intense thirst, dysphagia, anuria, and muscle pains. Gastrointestinal symptoms are variable and secondary to the neurological disturbances. In the terminal stages, the victim becomes progressively worse, finally developing muscular twitchings, convulsions, paralysis, and death by respiratory failure. The case fatality rate is about 8.5%.

The principal action of the poison is on the central and peripheral nervous systems, affecting respiratory and vasomotor centers, and neuromuscular junctions, cutaneous tactile endings, and muscle spindles. On this basis, one can consider it a neuromuscular poison, similar to curare, but having a more generalized effect (Kelloway, 1935; Fingerman *et al.*, 1953).

There is no specific treatment or antidote for paralytic shellfish poisoning. The gastrointestinal tract should be evacuated as rapidly as possible. Diuretics are indicated. Artificial respiration may be required.

(2) *Preventive Measures*

There should be strict adherence to local quarantine regulations in those areas where they have been established. At the present time, quarantine measures are established on the basis of toxicological surveys of the shellfish beds. This technique is inadequate and should be revised. Waiting for shellfish to develop a sufficiently high titer of poison is not satisfactory public health control. In at least one instance, there was a severe outbreak in the populace because public health sampling techniques failed to reveal a bed of shellfish containing lethal titers of poison. The shellfish were eaten and 32 persons intoxicated before sampling techniques indicated that a quarantine should have been established. Greater attention should be directed to fluctuations in the causative toxic dinoflagellate population along coastal areas where shellfish poisoning is known to be a problem.

Poisonous shellfish cannot be detected by their appearance, smell, or by discoloration of a silver object, and various other home detection methods. Safe testing requires laboratory procedures involving the use of mice or other laboratory animals. Ordinary cooking procedures do lower the toxin content, but not sufficiently for safe eating. The digestive organs, or dark meat, gills, and in some species, the siphons, contain the greatest concentration of the poison. The musculature or white meat is generally safe to eat. The bouillon or broth in which shellfish have been cooked can be extremely dangerous, since the poison is water-soluble.

(3) *Seasonal Fluctuation of Toxic Dinoflagellates*

The period when toxicity levels are highest varies somewhat according to geographical location. The dangerous period along the Pacific Coast of North America is from May through October. The Alaska clam, *Saxidomus giganteus,* maintains dangerous toxicity levels throughout the year. The most dangerous period along the east coast of Canada is during July through September. Occasionally there is some fluctuation in these cycles, and that is when difficulty is encountered. Most of the European and South African outbreaks take place during May through October.

(4) *Control of Toxic Shellfish Canning*

In the United States, toxicity standards for the amount of allowable poison in shellfish utilized for commercial processing are controlled largely by the Shellfish Sanitation Section of the United States Public Health Service. In Canada, shellfish toxicity controls are managed by the Department of Fisheries. Both countries require the toxicity level to be less than 400 mouse units per 100 g. of whole fresh, frozen, or canned shellfish. Minced or chopped clams, which are considered to be subject to less variation, are permitted to have a higher toxicity level, but must not exceed 2000 mouse units per 100 g. of contents. About 70% of the poison is destroyed during the commercial canning procedure. Research is currently in progress in an attempt to standardize bioassay techniques using purified paralytic shellfish poison as a reference standard (McFarren *et al.,* 1956). Additional controls are maintained by establishing quarantine, and thereby designating the time and place in which shellfish may be commercially taken.

(5) *Testing Methods for Paralytic Shellfish Poison*

Various methods have been used, but the following is the one generally accepted by most public health agencies. The shellfish are shucked, washed, drained, and then minced in a meat grinder. A 100-g. portion of the ground meat is added to 100 ml. of 0.1 *N* HCl and boiled gently for 5 min. with continuous stirring. After cooling, the mixture is adjusted to pH 4.0 or 4.5 with the use of 0.1 *N* NaOH or 5 *N* HCl, and then made up to 200 ml. with distilled water. A clear supernatant liquid is obtained by settling or centrifugation. A 1-ml. sample of the supernatant fluid is injected into each of 3 Swiss Webster white mice. A mouse unit is defined as the amount of poison present in a crude extract of 1 ml. necessary to produce a mean death time of 10 to 20 min. using 3 mice. The number of mouse units corresponding to various death times is determined by using tables based on Sommer and Meyer's (1937) graph. In order to obtain the toxicity per 100 g. of meat, it is necessary to multiply the number of mouse units contained in 1 ml. by 200, the combined volume of 100 g. of meat plus 100 ml. of dilute acid (McFarren *et al.,* 1956). Recently, this bioassay method, after minor modifications, has been adopted as official after extensive testing (McFarren, 1959).

(6) *Chemistry*

The exact nature of the poison has not been completely defined. Its toxicity is said to surpass any other known alkaloid. The toxin is dialyzable and has a specific rotation value of 130 degrees ± 5. It is soluble in methanol, hot ethanol, aqueous acetone, glacial acetic acid, and acidified water, but is insoluble in ether, chloroform, and the hydrocarbon solvents. For a more complete review of the chemistry of paralytic shellfish poison, see Schantz *et al.* (1957), Mold *et al.* (1957), and Courville *et al.* (1958).

A colorimetric test for the determination of shellfish poison has been developed. This test depends on the selective absorption and elution of the poison from a trichloroacetic acid extract of clam meat on a specific ion-exchange resin. The eluate is submitted to a probe of identity by applying the Jaffe test (McFarren *et al.*, 1958), later modified to suit this purpose still better (McFarren *et al.*, 1959).

b. VENERUPIN POISONING

This is an unusual form of shellfish poisoning, which so far has been restricted to certain brackish-water areas of the Shizuoka prefecture in Japan. Three species of shellfish have been incriminated thus far, namely, the Japanese oyster (*Crassostrea gigas*), Japanese dosinia (*Dosinia japonica*), and asari (*Tapes* [formerly called *Venerupis*] *semidecussata*). Poisonings have occurred only during the period from January to April. The primary cause and nature of the poison are not known. No relationship between plankton and shellfish has been found. Bacteriological tests for human pathogens have been essentially negative. The poison is concentrated primarily in the hepatic organ of the shellfish.

The incubation period is usually within 24 to 48 hr. The initial symptoms consist of gastrointestinal upset, headache, and malaise. Various types of bleeding disturbances are generally noted. The poison appears to be organotropic, affecting largely the liver (Akiba, 1943, 1949; Akiba and Hattori, 1949; Hashimoto *et al.*, 1950; Hashimoto and Migita, 1950; Hattori and Akiba, 1952).

Several efforts have been made to obtain the causative agent in a chemically pure form. In attempts to use treatment with benzoic acid, the typical venerupin was lost, and in its place a muscarine-like poison appeared (Migita *et al.*, 1956).

c. CEPHALOPOD POISONING

A large series of intoxications of unknown etiology has been reported from eating fresh squid (*Ommastrephes sloani pacificus*), and octopus (*Octopus vulgaris, O. dofleini*), in the Niigata, Yamagata, and Nagano prefectures of Japan. Gastrointestinal upset is the predominant manifestation. Most of the victims recover within 48 hr. The case fatality rate is less than 1%. All poisonings have taken place from June to November. Bacteriological tests and chemical examination for the presence of amines have thus far been negative (Kawabata *et al.*, 1957).

d. MINAMATA DISEASE

This is a little-known type of neurological disorder resulting from the ingestion of fish or shellfish taken from Minamata Bay, Kyushu, Japan. The disease was first reported in 1953. The exact cause of the intoxication is not known, but it is believed to be due to a chemical contaminant in the water which is ingested by marine organisms and retained in their bodies (McAlpine and Araki, 1958; Kitamura *et al.*, 1957). The poison seems to affect principally the central nervous system, causing cellular degeneration in the granular layer of the cerebellum, basal ganglia, hypothalamus, midbrain, and cortex, and other pathological effects. Clinically, the disease is described as a severe toxic encephalopathy characterized by symptoms of numbness, slurred speech, ataxia, deafness, disturbances of vision, hypersalivation, emotional lability, tremors, choreiform or athetosic movements, hemiballismus, etc. In most instances, cerebellar signs seem to dominate the picture. A number of fatalities have occurred.

3. *Poisonous Fishes*

A wide variety of illnesses caused by the eating of fishes has been reported in the medical literature over the past two hundred years. A general lack of understanding regarding the nature of these intoxications has resulted in much confusion regarding the terminology used to describe these disorders. Therefore, the following classification has been developed with the hope of clarifying the matter. The system is admittedly an artificial one, based upon clinical manifestations and the source of the poison. Present knowledge regarding the chemical and pharmacological properties of these poisons is as yet too meager to permit a more definitive classification. Additional information relating to some of these categories is available in reviews by Fish and Cobb (1954), Mills (1956), Anonymous (1957), and Halstead (1958).

a. ICHTHYOSARCOTOXISM

This general category includes intoxications caused by eating the flesh of poisonous fishes, i.e. musculature, viscera, skin, etc. This particular category of fish poisoning is characterized by the variety of places in the body of the fish in which the poison may be found. In other words, ichthyosarcotoxins are not restricted to any particular organ of the fish body. Included within this category are a variety of specific types of ichthyosarcotoxism. They are as follows.

(1) *Lamprey and Hagfish Poisoning*

The slime and flesh of certain lampreys and hagfishes are reported to produce a gastrointestinal upset. No neurotoxic symptoms have been reported. The nature of the poison is unknown.

(2) *Elasmobranch Poisoning*

The flesh of some sharks and rays is dangerous to eat. Tropical sharks and one such species from the Arctic (*Somniosus microcephalus*—the Greenland shark) are especially dangerous. Several deaths have been reported from eating the livers. Gastrointestinal symptoms usually predominate in mild cases, but neurotoxic symptoms are most pronounced in severe cases. The nature of the poison is unknown.

(3) *Chimaeroid Poisoning*

Some of the chimaeras or ratfishes have been incriminated as containing a neurotoxin. No clinical data are available, and the chemical nature of the poison is unknown. The viscera of these fishes are believed to be especially dangerous.

(4) *Moray Eel Poisoning*

Some of the larger moray eels, particularly of the genus *Gymnothorax*, inhabiting tropical reefs, may contain a violent neurotoxic substance. Intoxications are manifested by motor paralysis and convulsions predominating in severe cases. A variety of other symptoms such as gastrointestinal upset, paresthesias, and motor incoordination may also be present. The relationship of this poison, if any, to the ciguatera type of fish poisoning is not known. Moray eel poisoning resembles ciguatera quite closely, but the symptoms are almost consistently more severe, and the mortality rate higher. Whether this represents a greater concentration of the poison or a chemical difference is not known.

(5) *Ciguatera*

More than 300 species of marine fishes distributed throughout the orders Isospondyli, Apodes, Mesichthyes, and Acanthopterygii have been incriminated in human intoxications. Some of the varieties involved are: sea bass, jack, barracuda, snapper, wrasse, parrot fish, and surgeon fish. The barracuda poison was recently studied by Hashimoto (1956). The disease is most common in tropical areas (Arcisz, 1950). Both gastrointestinal and neurological disturbances are present, but paresthesias, extreme weakness, joint aches, muscle pains, and disturbances in temperature sensation dominate the clinical picture. The case fatality rate is less than 10%.

This is an extremely treacherous form of fish poisoning. Without a single known exception, the fishes producing this form of poisoning are edible in some areas, but toxic in others. Moreover, the toxicity in some regions seems to shift from time to time. Ciguatera constitutes a serious economic and public health threat to the future development of shore fisheries in tropical regions.

Tentatively Randall (1958), in an extensive review of available data, suggested that ciguatera might be explained by the transfer via fishes of a toxin produced by certain blue-green algae. The Soviet scientist Vinberg (1954) explains the mysterious Baltic Sea Haff disease on a similar basis, although the symptoms in this case do not coincide with those for ciguatera. Haff disease also occurs in Swedish and Russian lakes, after luxuriant blooms of blue-green algae.

Information concerning the physical and chemical characteristics of ciguatera toxin is extremely meager. Based on the examination of only very crude preparations, the poison is soluble in such solvents as methanol, ethanol, acetone, ether, chloroform, carbon tetrachloride, hexane, petroleum ether, benzene, and ethyl acetate. It is insoluble in water and dilute aqueous solutions of sodium hydroxide and hydrochloric acid. These solubility data indicate that ciguatera toxin is lipoid in nature but probably is not a phospholipid, and that the molecule evidently contains no acidic or alkaline functional groups. The toxin is heat-stable and shows a measure of sensitivity to oxygen. The poison is generally not destroyed by ordinary cooking procedures.

(6) *Puffer Poisoning*

The most violent form of fish poisoning is produced by tetraodontoid fishes, namely puffers (*Tetraodon* spp.), sharp-nosed puffers, ocean sunfishes, and porcupinefishes (*Diodon* spp.). The majority of the human intoxications are due to puffers of the families Lagocephalidae and Tetraodontidae. Gastrointestinal upset may be present, but is not significant. The neurological disturbances develop rapidly, and are generally violent, consisting of parasthesias, motor paralysis, convulsions, and death by respiratory failure. The case fatality rate is about 60%. If the victim survives the first 24 hr., the prognosis is good.

The empirical formula and structure of puffer poison have not been fully established. Two forms of the poison have been recognized. The more potent form favors the formula $C_{12}H_{17}O_{10}N_3$, whereas the less potent form is said to be $C_{11}H_{19}O_8N_3$. This poison has been studied to a greater extent than any other type of ichthyosarcotoxin. A more complete review of the chemical nature of tetraodontoxin or puffer poison has been presented by Courville and associates (1958). Indian cases of tetraodontid fish poisonings were studied by Jones (1956).

(7) *Scombroid Poisoning*

On rare occasions, scombroid fishes, i.e., tuna, skipjack, bonito, and mackerel, may cause ciguatera, but more frequently they cause an entirely different form of intoxication. This is the only known type of fish poisoning in which bacteria are directly concerned with the production of the poison. When scombroid fishes are kept at room temperature, a toxic, "histamine-like" substance is developed within the musculature of the fish. This substance is believed by Geiger (1944a, b; 1948) and Geiger *et al.*, (1944) to be produced by a decarboxylation of histidine through the activity of bacteria. He has shown that the "histamine" content of the flesh of the Pacific maçkerel, *Pneumatophorus diego,* increases from 0.09 mg. per 100 g. of tissue to about 95 mg. per 100 g. when kept at room temperature (20–25°C.) for about 10 hr. More recently, the chemistry of the substance has been studied by Kawabata *et al.* (1955), who claim that this is not histamine, but rather a closely related substance which they have termed "saurine" (see further Chapter 9 for discussion of histamine in fish).

Clinically, scombroid poisoning produces symptoms resembling those of a severe allergy or histamine intoxication. Initial symptoms are frequently a "sharp or peppery taste," followed by headache, dizziness, abdominal pain, burning of the throat, difficulty in swallowing, thirst, and gastrointestinal upset. A severe urticarial eruption may develop, covering the entire body and accompanied by severe itching. Death due to suffocation and shock has been reported. However, the acute symptoms are generally transient, seldom lasting more than 12 hr. Antihistaminic agents are said to give effective relief.

(8) *Gempylid Diarrhea*

Some of the fishes of the family Gempylidae, the escolars, contain an oil within their flesh and bone marrow which has a pronounced purgative effect when ingested. Diarrhea develops rapidly, and is said to be without cramping or pain. Since there are no other untoward effects, ingestion of the oil can hardly be considered as an intoxication in the usual sense of the word.

b. ICHTHYOÖTOXISM

Ichthyoötoxism is a general term used to designate intoxications resulting from the ingestion of the roe of fishes. The poison is believed to be restricted to the gonads. Most of the fish causing this form of intoxication are fresh-water species, members of the groups Acipenseroidei, Subholostei, and Ostariophysi. Most of the reported intoxications have occurred in Europe and Asia from eating fresh-water bream (*Abramis*), barbel (*Barbus*), and fine-scaled carp (*Schizothorax*) (Phisalix, 1922). Only one marine species has been incriminated to date—a cabezon (*Scorpaenichthys marmoratus*) (Hubbs and Wick, 1951).

Symptoms consist of gastrointestinal upset, chest pain, dryness of the mouth, intense thirst, and ringing of the ears. In severe cases there may be muscular cramps, convulsions, coma, and death. Most victims recover within a period of 5 days.

There is a definite relationship between gonadal development and toxicity. Ichthyoötoxic fishes are most dangerous to eat during the reproductive period of the year.

There is little or no information available regarding the chemical nature of ichthyoötoxins.

c. ICHTHYOHEMOTOXISM

This is a general term used to designate intoxications resulting from the ingestion of fresh fish blood. Ichthyohemotoxism is exceedingly rare, and among the least known of zoointoxications. The most frequent cause of these poisonings has been the drinking of raw eel blood from members of the genera *Muraena* and *Anguilla*. Cooking and contact with gastric juices destroy the poison in most instances. Injection of ichthyohemotoxins into laboratory animals results in convulsions and death. Such disturbances as gastroenteritis, paresthesias, paralysis, and death have been reported in human beings. Raw eel blood placed on the tongue or in the eye is said to result in a severe inflammatory response (Camus and Gley, 1898; Steindorf, 1914). This is denied by Bandt (1952-1953).

II. Skin Disorders in the Fish Industry

Skin infections are among the chief occupational hazards of the fishing industry. Because of the nature of their work and certain adverse operational conditions, fishermen and fish handlers encounter a variety of skin irritants which are of minor concern to other occupations. Schwartz and Tabershaw (1945) have conveniently classified these dermatological conditions into several categories, as follows:

1. *Abrasions, lacerations, and fissures.* These are the most commonly contracted skin lesions. They are generally the result of handling fish spines, fishing gear, and other sharp objects.

2. *Secondary infections.* These infections are generally caused by staphylococci and streptococci. The constant irritation of oilskins rubbing against the skin results in a contamination and breaking-down of the skin.

3. *Bites and stings.* Injuries of this type may be caused by a variety

of invertebrates and fishes that are handled during the course of fishing. Serious inflammatory conditions may result from fish stings, even though the fish may not be a venomous species (Fisher 1956; Halstead 1959). Jellyfish stings can be very painful, and a few species may cause death.

4. *"Red feed" dermatitis.* This lesion is the result of handling mackerel or herring, during the period from June to September, which have been feeding on a reddish-orange crustacean, largely *Calanus* species. Handling this "red feed," together with gastric juices from the digestive tract of the fish, results in swelling, redness, and numerous superficial skin ulcerations. The lesions are found chiefly on the palms and along the sides of the fingers. Such "red feed" accelerates the proteolytic breakdown of the gastric wall, which explains the simultaneous ready appearance of gastric juices.

5. *Scombroid dermatitis.* The skin of scombroid fishes, tuna, skipjack, bonito, etc., contains a substance which is considered to be a primary irritant. Spoiled fish are said to be more irritating than unspoiled ones. Anyone working with ungloved hands with scombroid fishes for any length of time may develop this form of dermatitis.

6. *Erysipeloid.* This is an infective dermatitis due to an infection with *Erysipelothrix rhusiopathiae,* which also causes swine erysipelas. Most of the infections are localized on the hand, but may appear elsewhere on the body, and can lead to septicemia. This disease is most frequently contracted from handling gurry or the remains of any fish that have undergone putrefactive changes. A special study of this human and Dicks (1949) from Australia. Oppenheimer (1953) brought evidence disease spread by marine fishes and crustaceans has been made by Sheard that this organism grows well in a sea-water medium, which might indicate it could be a potential human pathogen of the sea, as such not requiring fish or related forms as conveyors. The pathogen also occurs in fresh water and, consequently, harasses fishermen in lakes and rivers. Several such cases were reported by Bandt (1952-1953).

7. *Skin cancer.* Persons exposed to an excessive amount of sunlight are apt to develop skin cancers. Exposure to tar over extended periods of time appears to be an additional contributing factor.

8. *Allergy.* Fish oils are a common cause of allergic skin manifestations in some individuals.

The treatment of skin lesions is varied and frequently complicated and is generally a matter which should be treated by the physician. Cleanliness, protection of the hands with rubber or plastic gloves, and protection from chronic irritants will do much to prevent skin disorders in the fishing industry.

III. Medical and Economic Significance of Poisonous Aquatic Resources

The medical importance of poisonous aquatic organisms has been continually pointed up whenever and wherever they have been encountered by man. Military troops dependent upon the availability of local fisheries supplies have frequently been harassed by the problem. The French, Russian, Japanese, and American navies have published manuals dealing with the dangers of these organisms. Ichthyotoxism has been a problem in Russia and elsewhere in Europe for many decades (Phisalix, 1922; Pawlowsky, 1927). Puffer poisoning in Japan has accounted for as much as 44% of all the fatal food intoxications (Halstead, 1958). Poisonous fishes may contribute to the overfishing of one area and the underdevelopment of the shore fisheries of another because of their presence. This is somewhat the situation at present in the Line and Hawaiian Islands (Halstead, 1957).

Biotoxicological surveys of the shore fishes of some of the islands of the tropical Pacific show the incidence of poisonous fishes to range from 29 to 75% (Halstead, 1958). Although the practical toxicity potential of these fishes is considerably less than the figures cited, it is, nevertheless, sufficiently high to be of practical importance when considered from the over-all viewpoint of commercial development and public health regulations. The monetary damage to the fisheries industry resulting from mass outbreaks of biotoxications can hardly be computed, dollarwise. As time goes on and human population pressures continue to exert their influence toward developing new fishing grounds and a broadened spectrum of fisheries products, it becomes urgent that more serious attention be given to this area of research by both public health and fisheries scientists.

A positive, and probably in the long run a more important, aspect of the problem is the latent potentialities of aquatic biotoxins as a new source of chemical and therapeutic agents. Many of these compounds possess powerful pharmacological properties which, for the most part, have not been evaluated as to their possible medicinal and industrial uses. Certainly the ocean with its myriads of plants and animals offers a vast, almost unexplored reservoir of little-known chemical agents that may some day contribute greatly to the cure of some of mankind's worst ills.

Finally, aquatic biotoxicology offers a great number of unsolved, complex biological and chemical riddles which constitute an intriguing challenge to research. This is an area of marine biology which so far has been largely ignored. It presumably will continue to remain in its present undeveloped state until teams of researchers consisting of ecologists, systematists, epidemiologists, chemists, pharmacologists, zoologists, and algologists are given the opportunities of interdisciplinary cross-fertilization and adequate budgetary support.

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CHAPTER 15

On Marine Fish Diseases

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I. Introduction

The diseases of marine fish may be classified as: (1) dietary; (2) produced by organisms; or (3) from atypical cell growths. This chapter consists mainly of a review of those diseases resulting from the activities of organisms. Microorganisms responsible for marine fish diseases may be bacteria, fungi, viruses, or protozoans. Larger parasites such as the trematodes, nematodes, cestodes, or crustacea are commonly found associated with fish, but little is known of their pathogenicity. However, a few of the trematodes have been reported to cause death of fish; e.g., *Benedenia melleni,* a monogenetic trematode, lives in the skin and eyes of fish, and *Cryptocotyle lingua* cercariae larvae localize and encyst in the skin, causing black spot disease. The larger external parasites, such as the copepod, the brachiurian *Argulus* or so-called "fish louse," have one characteristic in common, that is, they irritate or break the integument or epithelial layers, providing entrance for the smaller unicellular pathogens, and they may also be quite destructive. While this latter situation may be common in nature, it is quite difficult to document. It is possible that the larger parasites may shorten the life span of fishes.

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There is some difficulty in distinguishing between marine and fresh-water diseases in fish like salmon or eels which have their habitat in both spheres. This is also true of fish found in brackish waters.

The study of fish diseases as a whole has been a seriously neglected field. Very little effort has gone into the study of marine fish diseases. Most investigations have been undertaken sporadically, and Ross Nigrelli at the New York Aquarium and Reichenbach-Klinke from the Technical Institute at Braunschweig, Germany, have regularly made important contributions. Several books containing references to marine fish have been written on fish diseases: "Handbuch der Fischkrankheiten" by Hofer (1904), "Praktikum der Fischkrankheiten" by Plehn (1924), "Fischkrankheiten" by Schäperclaus (1941, 1954), "Culture and Diseases of Game Fishes" by Davis (1956), but these books have been devoted primarily to fresh-water fishes, or to exotic aquarium fishes, as in the book of this title by Innes (1952).

Most of the bacteria listed in this chapter are described in the sixth or seventh edition of "Bergey's Manual" (Breed *et al.,* 1948, 1957). The protozoans are described in "Protozoology" by Kudo (1954). The author makes no claim as to completeness of known or reported marine fish diseases.

The proceedings of a special conference on fish diseases held in Leningrad, March, 1957, covers both marine and fresh-water fishes and surveys in a comprehensive way Soviet investigations in this field (Pavlovskij, 1959). A special review is devoted to Soviet studies of the parasitology of marine fishes (Poljanskij and Byochovskij, 1959).

MARINE ENVIRONMENT

Because fish are found in both fresh water and salt water, and some species, such as the salmon, inhabit both environments at different stages of their life, it is important to describe the biologically important aspects of the environment. The following points must be considered in any discussion of fish diseases because the activities of microorganisms are directly influenced by the presence of salts, temperature, and pH. Basically, the marine environment is distinguished from fresh-water environments by the presence of an average of 3.5% of salts in the former. It is quite difficult for the biologist interested in estuarine environments to draw a line between fresh-water and sea-water environments. The proportion of salts in marine brackish water remains relatively constant, being influenced primarily by the types and quantities of salts in the diluting fresh water. Marine parasites may be killed in fresh water and vice versa.

A knowledge of the effects of temperature on the activities of bacteria is important to the understanding of bacterial diseases of fish. Usually, bacterial activities are enhanced by increasing temperatures. Thus, many bacterial diseases are more prevalent during warm summer months. The temperature in the marine environment will fluctuate during the day and season, and the degree of temperature change is proportional to latitude and depth of water. For example, in a temperate environment where the water is shallow or protected, near-shore areas may have a day temperature of 30°C. during the summer and be frozen during the winter. In the open sea the temperature is much more constant. During adverse temperature conditions in the natural environment, fish may move to deeper water where the conditions are more stable and where surface temperatures do not penetrate rapidly.

Sea water is normally considered buffered at approximately pH 8.2 by the carbonate system, although the activities of photosynthesis and respiration may change the pH as much as from 6.5 to 8.5 during a 24-hr. period due to the uptake and production of carbon dioxide. Again, the degree of change is directly related to the activities and abundance of organisms and the mixing of the water. Fish are sensitive to changes in pH (McFarland and Norris, 1958), and death may be correlated with acidosis or alkalosis.

It is a matter of opinion whether we use the term marine fish disease for the lesion disease of pike caused by *Vibrio anguillarum* in the Baltic Sea at a salinity of 0.6%. Some microorganisms such as *Bacillus salmonicida* which cause fish furunculosis may survive up to three days in sea water, but the disease only occurs in fresh-water salmonid fishes, whereas an organism such as *Ichthyosporidium hoferi* can cause internal and skin lesions in both fresh-water and sea-water fishes, although in the latter case future investigations might establish that the fresh-water and sea-water species of *Ichthyosporidium* are different (see further Chapter 16).

II. Methods of Study

Methods for the detection or study of microbial diseases are similar to those which are used in the medical laboratory. In accordance with Koch's postulates, a disease-causing organism can be defined, first, through isolating in pure culture, second, by producing the same disease in a healthy fish, and third, when reisolated from a second diseased fish. Nutrient medium with either distilled water or 75% sea water and various sources of amino acids or extracts from fish tissues may be used to isolate the microorganisms. Usually each microorganism requires a special medium for cultivation (Liston, 1957).

It is imperative that either very recently dead or, preferably, live fish be used for microbial examination for diseases. Normal fish have many bacteria living in the intestinal tract and on the surfaces of the integument which can overgrow the disease microorganisms within a short time after the death of the fish. The causative organism can be obtained with less time and effort if a live fish is examined. Usually the bacteria causing disease are difficult to cultivate and may require special growth factors. If an inspection of a fish reveals some commonly known disease organism such as *Pseudomonas ichthyodermis*, one may turn to the literature to find the proper medium, which for this particular organism is sea-water peptone. Rare disease organisms require experimentation in order to find the proper medium. Various staining techniques and microscopic examination may be used for the partial identification of bacteria. The acid-fast stain may be used to identify the *Mycobacterium* which produces tuberculosis. The gram stain may be used to study the gram-negative *Diplobacillus* which causes kidney disease.

Dead fish and even canned fish can be inspected for atypical cell growths or organisms which cause internal lesions. Infected tissues are sectioned, stained, and examined for the identification of organisms such as *Ichthyosporidium hoferi* or *Oodinium ocellatum* which can be identified by morphology. Usually those stains which are positive for nuclear material are used.

Virus diseases are difficult to study because of the minute structure of the causative organism. The presence of a virus disease is usually suggested when a specific disease-causing organism is not detected. The presence of a virus is proven when material from the diseased area remains infective after being passed through a bacterial filter. Special procedures are necessary for the cultivation and examination of viruses in the laboratory.

Protozoan diseases may be identified by their various forms during life cycles. Often the disease is recognized by the presence of a specific intermediate host such as the snail *Littorina litorea,* which is an intermediate host for the trematode, *Cryptocotyle linguae,* causing black-spot disease in herring, or the presence of the cysts of the dinoflagellate *Oodinium ocellatum* which are found on the aquarium bottom. Characteristics will be further explained in the section on protozoan diseases.

III. Bacterial Diseases

Although "red disease" in the common eel has been known since 1718, one of the first reports of a causative agent of a marine fish disease was that of Hofer (1904), who showed in 1877 that the "Lachspest" (ulcer) disease of salmon was caused by the organism *Bacillus salmonis pestis,* a short, thick, motile rod which grew in sea-water medium. Soon after this discovery, reports on the cause and diseases of fish in fresh-water culture ponds and streams became more numerous.

Bacteria are ubiquitous, microscopic, unicellular rods, spheres, or spirals which are found living in sea water and marine sediments. Water acts as a perfect vector for the bacteria that may exist either attached to larger particles or floating free in the water. Because they do not pass through an unfavorable atmospheric environment, as human pathogens usually do, it is easy to see how a fish pathogen can pass from one fish to another, except for the viruses, which are believed to pass directly from host to host. Many of the bacterial fish pathogens live as saprophytes in sea water and sediments.

Most marine bacteria contain or liberate proteolytic enzymes which actively decompose the fish proteins after the death of the fish. During life, however, the mucus, scales, and skin are an effective barrier to the action of destructive bacteria. Bacteria may gain entrance if the layers of the integument are damaged or removed, by punctures by fins of other fishes, by the abrasive effect of the sea bottom or aquarium, or by the action of parasites living on the fish surfaces.

A. *Vibrio* AND *Pseudomonas*

The "red disease" of the common eel, caused by *Vibrio anguillarum* (Brunn and Heiberg, 1932), has been known for more than 200 years. At times 30% of the inspected eels were infected. The disease is systemic, and the bacteria are thought to gain entrance through the gills or intestine. The disease is first noted by the occurrence of a red coloration at the tail or fin base which later spreads over the entire body. Eels normally die before the red coloration spreads over the entire fish. Microscopic examination reveals that tissues of the fish are congested with blood and contain the *Vibrio*. This disease occurs during the warm months and is primarily reported from Danish waters and surrounding areas, the Baltic Sea, and the Mediterranean. During the summer, the eel fishery suffers considerably because the European housewife purchases living eels and will reject those appearing abnormal. *Vibrio anguillarum* is also infective to young plaice and mature codfish (Dannevig and Hansen, 1952) and may cause extensive mortality in the aquarium. Its taxonomical characteristics have been studied by Nybelin (1935).

As a whole, it is considered halophilic and generally specific to eels. A recent epidemic (1959) was reported from the Baltic coast of Germany (Mattheis, 1960) after an interval of no less than 27 years with relatively low rates of incidence. High temperatures of surface waters are required to allow this agent to develop in great numbers. Warm weather consequently is a prerequisite. A toxin is produced with multiple effects on the eel, generally resulting in death. There are two types of this *Vibrio:* A and B, with slightly different physiological characteristics. An eel epidemic is generally followed in the next year by a pike epidemic (Mattheis, 1960).

The motile bacterium *Pseudomonas ichthyodermis*, which causes external lesions and death in many fish (Wells and ZoBell, 1934), has been found in both the Atlantic and Pacific Ocean, where it apparently is a part of the normal flora. For a limited time in the warm summer months the microorganism may cause severe damage to aquarium fish and then apparently loses its pathogenicity. Laboratory experiments by the author during one summer outbreak of the disease in the Scripps aquarium and in the natural environment revealed that the organism, isolated from fresh skin lesions, remained pathogenic for approximately two weeks. It lost its pathogenicity at about the same time that the lesions in aquarium fishes began to heal. During this time, free divers noted the rise and decrease in the incidence of fish with lesions in the vicinity of the aquarium. The latter example of the loss and gain of pathogenicity of a marine organism may be only one example of a common occurrence.

Hemorrhagic septicemia appears to be a common disease in both aquaria and natural habitat. It is easily noted by the presence of lethargic fish with external lesions or by surface bleeding. At times, freshly netted fish such as sardines will demonstrate external bleeding caused by mechanical abrasion from the net. This surface bleeding disappears after a short time in the aquarium. The disease, caused by bacterial invasion of tissues, is characterized by the bleeding and edema of internal tissues, although it is possible that an external bleeding of the skin resulting from the advanced systemic infections by *Pseudomonas, Vibrio,* and other undescribed organisms also may be classified under this disease. Several *Vibrio* and *Pseudomonas* species shown to be pathogens may form lesions, produce a general infection of other tissues, and finally cause a general septicemia just prior to death (Hodgkiss and Shewan, 1950). Several outbreaks of hemorrhagic septicemia accompanied by heavy mortality for salmon, herring, and sardines have been reported in the vicinity of the Washington State Fisheries Station (Rucker *et al.,* 1953). *Vibrio* species were found to be responsible for these diseases.

Other *Vibrio* may be the cause of widespread diseases (Rucker, 1959). Mass mortalities have been reported in the herring and pilchard population in Alaska and Vancouver Island waters, and in herring held in live bait tanks (Rucker *et al.,* 1953). The disease is similar to furunculosis and is spread by contaminated water or from fish to fish by predation. About 10% of the codfish caught off the south coast of Sweden between Ystad and Trälleborg had a *Vibrio* infection of the eyes (Rucker, 1959). Aquaria-held plaice had *Vibrio* infections involving 49% of the fish (Rucker, 1959).

B. FURUNCULOSIS

McGraw (1952) indicated that furunculosis, a common disease of fresh-water fish caused by *Aeromonas salmonicida,* is not found in the marine environment. The disease has been reported to be present in adult Pacific salmon (Wood, 1959). However, it is problematical whether the disease was caught in fresh water and then survived the exposure to salt water. The bacteria were isolated from lesions found in the kidney and soft, blister-like areas filled with blood just under the skin. It is quite possible that the disease was acquired after the fish entered the fresh water. This systemic disease has been extensively studied because of its prominence in hatcheries—see further Chapter 17.

C. TAIL ROT

Tail rot commonly occurs in fish kept in marine aquaria. It is also reported from natural habitats. Only two specific examples are given here. However, it is the author's opinion that this is a very common disease of marine fishes. Herring in tanks and sea water at Boothbay Harbor, Maine, repeatedly have had tail rot (Sinderman and Rosenfield, 1954). The first sign of the disease is a hemorrhagic area under the scales near the peduncle and a progressive growth of a lesion accompanied by the sloughing of scales. Most often this occurs at the base of the tail, although it may appear at other places on the body. The early stages of tail rot can easily be seen in the water but not as easily as when the fish are in air. As the disease progresses, there is a general sloughing-off of the tail region, and death occurs soon after. A gram-negative rod was isolated from the lesions and other external parts of the fish. Death is believed to be caused by a systemic reaction to the disease organism.

Tail rot is also quite prevalent in cod holding cages in Norway (Oppenheimer, 1958). The symptoms are identical to those described above, and the causative agent was found to be an organism similar to *Pseudomonas*. The disease causes some concern to fish handlers since the average Norwegian prefers to purchase living codfish for his table, and the diseased-fish are not eye-appealing, even though the causative organism is not pathogenic to humans.

D. Tuberculosis

Earlier incidences of tuberculosis in fishes were reviewed by Griffith (1930) and Aronson (1938). The first described case refers to carp (Bataillon *et al.*, 1897), and the first report of this disease from marine fish (cod) was provided by Johnstone (1913). A comprehensive recent review of this field of research has been presented by Parisot (1958).

The disease is characterized by internal lesions or dull white tubercles in the kidney, liver, spleen, and intestine. Occasional external lesions have been found. The acid-fast bacilli *Mycobacterium marinum* may be found in the lesions. The infected fish may appear normal and are not suspected of being diseased until tissue smears of bacteria are shown to be positive. Death is probably indirect, resulting from weakening of the fish, which easily become prey. The disease has been reported for the common eel, cod, sergeant major, croakers, black sea bass (Parisot, 1958), chinook salmon (Earp *et al.*, 1953), and several other species of marine fish. The organisms reported have not been pathogenic to man. The disease is probably transmitted by an infected fish when eaten by another fish.

In a study of salmonid fishes returning from the ocean for spawning in 1952-1956, a high incidence of tuberculosis was established. As the disease was confined to fish known to be of hatchery origin—in some cases 100%—the feeding of untreated carcasses and viscera from originally tuberculous fish was considered a prime factor (Wood and Ordal, 1958). Such a direct transfer of this disease from feed to young fish was reported by Baker and Hagen (1942).

E. Eye Infections

Eye infections in marine fish in aquaria and in the natural habitat are common. Very few reports have been published on the cause of the eye disease except for fresh-water fishes; the causative agent is thought to be

Ichthyophthirius multifiliis, Dermocystidium sp., *Ichthyosporidium hoferi,* and several bacteria, including *P. punctata* (Reichenbach-Klinke, 1954b). Fish death statistics from the New York Aquarium indicate that 0.32% of the fish died of exophthalmos or protrusion of the eyeball (Nigrelli, 1940). The disease in sea-water fish is characterized by a protrusion of the eyeball and subsequent loss of the eye or the growth of an opaque covering over the eye.

F. Kidney Disease

Kidney disease is common in salmon during hatchery procedures (Earp *et al.,* 1953). It is characterized by lesions of the kidney, liver, and spleen in which a small, gram-negative *Diplobacillus* is always found in large numbers. The disease is usually confined to fresh-water aquaria, although it will continue when the fish are placed in sea water. It may also be pertinent that the *Diplobacillus* will grow in sea-water medium. The *Diplobacillus* is always present, but investigators are not certain that the microorganism is the primary disease agent.

G. Miscellaneous Bacteria

Several other bacteria have been reported to cause fish death but have been little studied. *Treponema cotti, T. pavonis, T. triglae,* and *T. perexile* have been found in the intestine and blood of the marine bullhead, blenny, and other marine fishes (Breed *et al.,* 1948). *Spirochaeta aeglefini* and *S. gadi* have been found in the blood of haddock and cod. The descriptions of these organisms in the sixth edition of Bergey's Manual were not sufficient to be included in the seventh edition. It is problematical whether the microorganism caused death of the fish, but it is interesting to note that such microorganisms have been found.

Recent studies have shown that *Flavobacterium piscicida* isolated during a red tide outbreak along the Florida Coast produces a compound, possibly a neuromuscular toxin, which is toxic to marine fish (Meyers *et al.,* 1959). It is not unreasonable to assume that the by-products of some bacteria may be toxic to marine fish in unusually large plankton blooms where the toxic material is concentrated. However, large growths of bacteria are only found in the sea where planktonic blooms are present. In occurrences of red tide where organisms such as *Gonyaulax* or *Gymnodinium* have produced materials toxic to fishes (Galtsoff, 1954), it is quite difficult to distinguish other toxins produced by bacteria. By-products from toxic bacteria may also cause death of fish as reported in a preceding paragraph.

Inclusion bodies resembling *Rickettsia* have been found in the leucocytes or distributed in the plasma of the blood and kidney of *Tetrodon* *fahaka* (Mohamed, 1939). The fish had died for some unknown reason. On either side of the head and body there appeared several necrotic ulcers which resembled an ulcerative dermatitis. Cultures made from the liver and blood were negative for bacteria. No conclusive evidence for a Rickettsial disease was found other than the presence of the inclusion bodies, which were not normal for other similar fish.

Chondrococcus columnaris is causing concern to the canners on the Columbia River. This bacterial disease has become prevalent among the blueback salmon migrating up this river for spawning. It is known that this disease is contracted in warm waters (Anonymous, 1960).

IV. Virus Diseases

In general, there have been very few reports of viruses in the marine environment (Watson, 1953). The most noteworthy disease caused by a virus is Lymphocystis found in flounder, and many other marine fish (Nigrelli, 1940; Weissenberg, 1949). The disease is widespread, found in both fresh-water and marine fishes, and is characterized by the appearance of nodules on the body or fins, which in severe situations may cover most of the fish. The virus, which can be seen as inclusion bodies in the nodules, stimulates growth of fibroblast cells in the connective tissue which enlarge sometimes up to 2000 microns during a year. The enlarged cells surrounded by a thick transparent membrane are called lymphocystis cells. Desiccated pieces of the nodule placed in the tissue of other fish will experimentally cause infection. Bruised fishes will be infected if placed in water containing an emulsion of lymphocystis material. The virus organisms pass through a Chamberlain filter. High mortalities have not been common, and it is assumed that most detrimental aspects of the disease arise from predation of the diseased fish.

V. Fungi

The most common fungus disease of marine fish so far known is caused by systemic infection of *Ichthyosporidium hoferi,* reported in 1893 for fresh-water fish and later found in such marine fishes as flounder, haddock, mackerel, and herring (Sindermann and Scattergood, 1954; Gustafson and Rucker, 1956). Its occurrence in the Mediterranean has been subject to a special investigation by Reichenbach-Klinke (1957). He also discussed trends as to its distribution in this important basin. Two epidemics (in herring) have been reported (Sindermann and Rosenfield, 1954). The greatest infections occur near shore in late winter and early spring. The disease produces marked changes in the tissue as well as changes in behavior; e.g., erratic swimming motion. A sandpaper effect—roughening of the skin—usually in the lateral regions, is the first external evidence of disease. The effect is due to the presence of small, raised papules caused by the rapid growth of the fungus under the epidermis. When the papules perforate the surface of the epidermis, small black areas are revealed. The small black areas should not be confused with the similar effect caused by trematode metacercariae which encyst under the epidermis (Sindermann and Rosenfield, 1954). In later stages the epidermis sloughs off as necrosis becomes more extensive and lesions are formed.

In addition to the external effects, gross infections occur in muscle and internal organs. The internal lesions have the appearance of white nodules as large as a centimeter in diameter. The heart is usually the first organ to be affected, and the small nodules may grow until the heart is enlarged several times and is completely covered by a white fungus mat. The external and muscular infections are more common in the herring and often absent in the mackerel and flounder. At times the myxosporidian *Chloromyxum clupeidae* will produce pus pockets in the muscle of herring which are similar to fungus nodules.

The fungus may be found during the microscopic examination of stained sections of the fish. Both round, sporelike bodies (10 to 250 microns) and fungal elements may be demonstrated. Single spores are indicative of an early infective stage, and the presence of filaments indicates advanced infection. The infection is spread through the fish by the distribution of the spores through the blood. Evidence of infection was noted within 30 days in fish inoculated with the fungus. Spores attached to copepods eaten by the fish were also a source of infection. Infective spores were liberated to the water from skin lesions or after decay of infected fishes.

Reichenbach-Klinke (1954a) reported the presence of a fungus in gill tumors of codfish. It was not possible to determine whether the fungus was the primary or secondary cause of the tumor.

Saprolegnia is a common fungus parasite of fresh-water fish which grows as a white, cottony mat on the surface of the fish and infiltrates into the integument and muscle. The parasite may be found in brackish-water fishes (Vishniac and Nigrelli, 1957). Earp *et al.* (1953) found that *Saprolegnia* disappeared when infected chinook salmon were placed in sea water.

VI. Protozoans

The author is not cognizant of any protozoan diseases of fish which have been reported to have man as a host. Most of the protozoan parasites are host-specific, although some are not; *Eimeria clupearum* lives in the liver of herring, mackerel, and sprat, and *Ichthyophthirius multifiliis* and *Oodinium ocellatum* are parasitic to many species of marine fish. *Eimeria* may be found in the feces of human beings who have eaten infected fish. However, the spores of the *Eimeria,* common to commercial marine fishes, may pass through the digestive tract of man and appear in the feces (Kudo, 1954).

It is quite possible that protozoans such as the myxosporidian *Henneguya* may incite the formation of tumor growths such as have been reported for the papillary cystic disease of catfish. The parasite causes the formation of fibroblasts which replace tissue.

Protozoans are currently classified into Mastigophora, Sporozoa, Sarcodina, Ciliata, and Suctoria. Most families of the protozoans have been found indigenous to the marine environment, and it is therefore not unreasonable to anticipate that most forms parasitic on fresh-water fish will have marine counterparts. The Sporozoa are, without exception, parasites. Protozoa representing all classes except Suctoria have been reported to be parasitic to marine fish. Although many of the parasites do not appear to cause death directly, they may act as loci for infections by bacteria or fungi. Epidemics have been caused by the sporozoans (Myxosporidia and Microsporidia) endoparasites of several marine fishes. Most of the protozoan parasites are hyperinfective in marine aquaria where they are in constant contact with the fish during the life cycle of the microorganisms. In the environment, reinfection of the host by its parasites may be rare because the fish will move away during the various metamorphic changes of most of the protozoans. Perhaps for this reason most of the parasites do not cause extensive damage in nature unless crowded conditions exist, as in schooling behavior. The endoparasitic forms are often overlooked because microscopic observations are needed to detect the causative microorganisms. The exoparasites appear as growths, open sores, or pustules which can usually be seen without microscopic examination.

A. Mastigophora

Three species of the class Mastigophora are known to parasitize marine fish. *Amoeba,* although found in fresh-water salmonid fishes, has not been found in marine fish. The dinoflagellate *Oodinium ocellatum* is commonly found in marine fish in tropical waters, during temperate summer temperatures, and in aquaria (Nigrelli, 1936, 1940; Kudo, 1954; Dempster, 1955; Reichenbach-Klinke, 1956). *Oodinium* is a free-swimming dinoflagellate which attaches to the gills of the host fish by cytoplasmic processes. Occasionally the organisms attach to other parts of the integument. The parasite can cause extensive damage in closed aquaria because the mature organism falls off the gills to the sea bottom or aquarium floor where it goes through its life cycle and is infective. The organism enlarges, and the cyst contents divide into 128 flagellated cells, which further divide into 256 free-swimming flagellates capable of reinfecting the host. The infection impairs the normal gill function and when severe may cause death.

Trypanosomes have been found in the peripheral blood and *Protrichomonas* in the esophagus of marine fish, but little is known about the toxicity of these organisms to the host. Trypanosomes have been reported for many years from marine fish of European waters (Lebailly, 1904; Neumann, 1909), and a number have been described from similar hosts in Africa (Fantham, 1919; 1930), Australia (Mackerras and Mackerras, 1925) and New Zealand (Laird, 1951). Only a few, however, have ever been encountered in marine fishes of the United States (Saunders, 1959). Such trypanosomes were found in a winter skate, *Raja ocellata* Mitchill, from Woods Hole, Massachusetts, and were identified as *T. rajae* (Laveran and Mesnil, 1902). Bullock (1958) also reported it from the common skate *Raja erinacea* Mitchill, from southern New England. *Trypanosoma rajae* and *T. giganteum* are found in the ray *Raja oxyrhynchus. Trypanosoma granulosum* has been reported in the eel (Kudo, 1954).

B. Sporozoa

Sporozoan protozoans may cause extensive damage to natural fish populations. Walford (1958) lists some of the Myxosporidia and Microsporidia which have been reported to be parasitic to marine fishes. These organisms are endoparasites which invade the tissues of the host fish. Because the life cycle varies, the free-existing mature cysts in general are taken into the gut of the host with food or in connection with other activities. The cysts germinate into sporozoites which penetrate the epithelial cell or other host tissues, depending on species. Each organism then matures through several stages and eventually ruptures the host cell to liberate oocysts or spores. The spores are quite resistant and may exist in rather unfavorable environments and still be viable. The spores of the sporozoans are quite typical, having the appearance of symmetrical asterisks or petal arrangements of 4 to 6 segments separated by a suture.

The coccidian *Eimeria* has been found in the testes of sardines, the liver of herring, mackerel, and sprat, and the swim bladder of cod and the testes of menhaden.

The presence of haemogregarines in the blood of fishes was first reported by Laveran and Mesnil (1901) from France. Since that time, other occurrences have been reported spasmodically from a few other countries. There is an uncertain record of its possible observance in eastern Canada (Fantham *et al.*, 1942). Laird (1951), who made the first systematic study of this group, found a considerable number in the fishes of New Zealand and the Fiji Islands. Kudo (1954) states that it occasionally occurs in the blood of soles. The first recorded finding from the United States dates from 1955 and only in low frequency (Saunders, 1955).

Some sporozoans are capable of excreting a powerful proteolytic enzyme which digests muscle. Soft, mushy white areas in muscle, caused by *Chloromyxum* and *Hexacapsula,* have been reported in hake, swordfish, Japanese sea bass, and yellowfin tuna (Fletcher *et al.*, 1951; Matsumoto, 1954). In one instance in North Africa, 40% of the hake were infected.

The jellied condition of swordfish was originally attributed to *Chloromyxum* sp. (M'Conigle and Leim, 1937). Subsequently, Arai and Matsumoto (1953) discovered that in yellowfin tuna the active agent was *Hexacapsula neothunni.* Such jelly-like meat has been observed in a great many food fishes besides the two mentioned, such as halibut, turbot, and other tuna-like fishes. The causative microorganism has in general not been identified, frequently under the supposition that this radical change in texture was due to some unexplained biochemical activity, presumably of an enzymatic nature and constituting part of the autolytic breakdown of the tissue (Tsuchiya and Tatsukawa, 1954; Tsuchiya and Kudo, 1957).

The myxosporidian *Chloromyxum thyrsites* has been reported from the following South African fishes: snoek (barracuda), hake, and John Dory. This organism also is found in the pilchard and the maasbanker (horse mackerel) (Rowan, 1956). Pilchard tissue with more than two million spores per gram collapses and turns mushy when canned or otherwise processed (Rowan, 1956). This tissue breakdown through these sporozoans is generally attributed to proteolytic enzymes acting extremely rapidly. Whole fish can be decomposed within 24 to 70 hr. at normal temperature. *Chloromyxum clupeidae* causes ulcer disease of herring (Sindermann and Rosenfield, 1954). Only circular exterior ulcers are present, and internal lesions have not been noted.

The common haddock parasite—a myxosporidian, *Myxobolus aeglefini*—occasionally is encountered in the cranial tissue of such other fish as the plaice, thus emphasizing the opinion upheld by several fish pathologists that sporozoan parasites tend to be tissue- rather than host-specific (Kabata, 1957).

Certain boreo-arctic microsporidians have been studied by Kabata (1959) and reported from such far-separated regions as the White Sea, Iceland, and the Gulf of St. Lawrence.

The microsporidia are widely distributed as parasites of fish. They invade and undergo asexual division and sporogony within the host cell. The host's invaded cells become hypertrophied. The organisms are small spores, 3 to 6 microns in diameter. The spores are easily identified by the presence of an outline or ridge which separates the spore into two halves. The spores, taken into the intestinal tract, pass through the epithelium, enter the blood stream and reach the specific site of infection. *Glugea* has been reported in the mucosa of the gut of smelt, stickleback, and plaice (Kudo, 1954 and Bückmann, 1952).

Certain myxosporidian sporozoans appear to be host-specific for the tissues of specific marine fish. Thus, the tapioca disease of salmon is caused by *Henneguya salminicola* (Kudo, 1954). Severe epidemics of wormy Pacific halibut have been reported to be caused by muscle invasion of *Unicapsula muscularis* (Kudo, 1954). At times, 5% of the catches of barracuda contain infections of *Kudoa thyrsites,* which causes the muscle fibers to turn milky and soft (Kudo, 1954). Other species of *Kudoa* have also been found in body muscles of marine fish. *Sphaeromyxa* have been found in the gall bladder of *Motella* and other marine fish of Europe, and *Siphostoma* appear in United States fish. To show the complexity of nature, it has been reported that the urinary bladder of the toadfish *Opsanus tau* is parasitized by the myxosporidian *Sphaerosphora polymorpha.* The trophozoite of the parasite is then parasitized by the microsporidian *Nosema notabilis.* The microsporidian parasite does not directly infect the tissues of the host fish.

Lentospora cerebralis (now known as *Myxosoma,* according to Kudo, 1954) has been found to cause twist disease in herring reared in aquaria (Dannevig and Hansen, 1952).

The gall bladders of sharks, rays, *Gadidae,* and *Cyprinidae* in the Mediterranean have been parasitized by the myxosporidians *Leptotheca, Sphaerospora, Ceratomyxa,* and *Chloromyxum* (Theodorides, 1955). *Sinuolinea* has been located in the urinary bladder of marine fish.

Six species of the fish-inhabiting Cnidosporidia invade the cranium of several fish species, which not infrequently is found filled with a mass of soft substance constituted of spores. Such sporozoans are reported from cod, haddock, plaice, hake, etc.—for further reference see Kabata (1957). It is possible that several of these species are tissue- rather than host-specific.

C. CILIATA

The round ciliate parasites *Ichthyophthirius* are a common cause of death in aquarium fishes. Marine fishes are parasitized by euryhaline species. The free-swimming ciliate enters the integument, where it forms a cyst, feeds on the host cells, and forms white or grey pustules. When the cyst develops into a mature trophozoite, it drops from the fish to the aquarium bottom, where it encysts and divides into young ciliates, which break through the cyst wall and may reinfect the host. The barrel-shaped ciliate *Trichodina* has been reported to infect puffers of Sand Hook Bay and is assumed to be a source of infection for other fish (Nigrelli, 1940).

VII. Larger Parasites

It is problematical whether extensive mortality in the natural environment occurs from the infestations of larger parasites. In crowded hatchery conditions, the infestations of the larger parasites may often cause death. Reports on the occurrence of helminth and crustacean parasites are so numerous that it will be pertinent to mention a few representative groups.

In general, the larger parasites fall into three groups: flatworms (Platyhelminthes), roundworms (Nemathelminthes or Acanthocephalians), and copepods (Arthropoda). Most students of biology are familiar with the flukes and tapeworms. External-living flukes or trematodes, such as the monogenetic forms, may live in the gills, while digenetic forms live in the intestinal tract; some exceptions have been noted. Some flukes may be infective to man, for example, *Heterophyes heterophyes*, present in the common mullet (Belding, 1942).

A. Trematodes

The flukes are short, elongated to oval forms, flattened dorsoventrally, and are surrounded by a cuticle in place of epithelial cells (Hyman, 1951; Koratha, 1955). They are hermaphroditic, producing eggs surrounded by a capsule. Having only one host, the eggs develop directly into an adult form. Flukes move on the host by a looping manner and feed on slime epithelian cells and blood exuding from places damaged by the parasites' hooks and suckers (Llewellyn, 1957). They attach to the host by means of suckers, but some species have hooks or spines. The monogenetic trematodes are primarily ectoparasitic, inhabiting the gills and occasionally the skin of fish. *Benedenia melleni* caused death in aquaria-held spiny-rayed fishes (Nigrelli, 1940). The digenetic flukes are generally endoparasites which live in the intestinal tract of the fish. They have a more complicated life cycle, including several metamorphic forms, and require up to four intermediate hosts.

Occasionally the intermediate stages of the trematodes may be disease agents, such as the cercaria stage of the *Cryptocotyle lingua* (Sindermann and Rosenfield, 1954). This organism invades and encysts just under the epidermis, causing the area to become black, and thus creates "pigment spot" disease. Infection occurs in inshore waters where the snail *Littorina litorea* is found. The hosts, during the life cycle of the trematode, are the snail, the gull or tern, and the herring. Massive infections may cause death of the herring.

There are numerous descriptions and records of the trematode parasites of marine fish from various parts of the world. The majority of these have been conveniently summarized and reviewed by Dawes (1946, 1947), Yamaguti (1953), Skrjabin (1947-1955), and Manter (1955). Philippine food fishes were investigated recently with regard to the trematode family Bucephalidae Poche 1907 (Velasquez, 1959). Nagaty (1957) found several trematodes on fish in the Red Sea. A comprehensive study of diseases and parasites of marine animals off Florida has resulted in the reporting of a great number of trematodes from marine fish (Sogandares-Bernal and Hutton, 1959). *Schistosoma cercariae* may be so common as to cause skin disturbances in man (Hutton, 1952).

A number of digenetic trematodes with high degree of host-specificity have in latter years been described from the West African coast (Thomas, 1959) from an area very poorly investigated earlier. In general, this supports the contention of Manter (1955) that host-specificity is of a high order among digenetic trematodes of marine fishes, particularly among those living in warm waters. The widespread geographical distribution of *Lasiotocus longicaecum* and the remarkably close resemblance of the forms on both sides of the Atlantic with those in the Pacific indicate that this species is monotypic. This coincides well with the low degree of host-specificity and with the free-ranging habits of the host fishes (Thomas, 1959).

An investigation of monogenetic trematodes in the Gulf of Mexico is underway. Several papers have been published—for further references see Hargis (1955). The monogenetic *Kuhnia scombii* is a common parasite of the gills of the Atlantic mackerel. A recent study was devoted to its attachment mechanism (Llewellyn, 1957).

B. CESTODES

The tapeworms are endoparasites of many fish. They have no epidermis, mouth, or digestive tract and attach to the host by means of suckers and hooks in the anterior end. The body is divided into segments or proglottids which are hermaphroditic, producing encapsulated eggs. Some species cast off the gravid segments. They require intermediate hosts to complete their life cycle (Hyman, 1951). Food is obtained by direct absorption through the surfaces of the segments. The head, or scolex, may be able to absorb food through the sucking disc.

The tapeworms, or cestodes, generally inhabit the intestinal tract of the fish. Thus, the scolex of several cestodes has been reported from the intestine in some fifty different species covering a wide area along the coasts of Europe, the Atlantic coast of North America, and the Arctic Ocean (Rees, 1958). *Bothriocephalus scorpii* has been found in the Atlantic herring (Dollfus, 1956) and halibut (Rees, 1958). Cestodes are quite common in marine fish of India (Kambata and Bal, 1952, 1954; Rao, 1954; Ganapati and Rao, 1955). Some forms are found in the muscle such as *Poecilancistrium robustum,* the spaghetti worm, which reaches lengths of 17 cm., embedded in the muscle of many species of fish in the Gulf of Mexico (W. N. McFarland, personal communication). The presence of the worm is annoying to anglers, although not harmful to man. At times, 44% of a catch may be infected by as many as 5 worms per fish, while occasional large specimens of the croakers, *Cynoscion nebulosus* and *Pogonius chromis,* have upwards of 100 worms. The tapeworm *Diplogonoporus grandis* lives as an intermediate host in marine fish and has infected humans in Japan (Belding, 1942). The plerocercoid larvae, wormlike in appearance, are found in the flesh of many species of fish. An important focus for tapeworm infections in man is the semi-saline Baltic, particularly the Finnish Bay, according to Soviet investigations. *Diphyllobotrium* is the dominating species. Pike, pope, and turbot are the most affected species (Engelbrecht, 1958). See further Chapter 16, of this volume.

Elasmobranchs appear to be more heavily infested than teleosts (Robinson, 1959). Some important recent studies from various geographical areas are the following: Canada, Wardle (1932); New Zealand, Robinson (1959); India, Rao (1957) and Subhapradha (1955).

C. NEMATODES

Nematodes or roundworms are commonly found in marine fishes (Kahl, 1939; Rees, 1946; Olsen, 1952; Chalupsky, 1955). The sexes are separate and they have a simple life cycle. The worms are cylindrical, the anterior end equipped with hooks or teeth. A digestive system is present, and food is acquired from tissues and intestinal contents. Food may be absorbed through the epidermis.

In most of the Gulf of St. Lawrence and in some other marine areas of eastern Canada, the infection of the flesh of cod with larval nematodes —chiefly *Porrocaecum decipiens* (Krabbe)—constitutes a considerable economic problem (Heller, 1949; Templeman *et al.*, 1957; Scott and Martin, 1957, 1959). Seals are the hosts for the final adult stage, releasing eggs which reinfect young fish. The infection level is related to the prevalence of seals, chiefly three species. The relative importance of each seal species, as to the incidence of larval nematodes in cod from different fishing grounds off the Canadian Atlantic mainland, was studied by Scott and Fisher (1958). In all areas studied, there is an increased incidence of infection with age. In latter age groups, 70% of the cod were infected. No direct relationship was established between the frequency of this nematode in cod flesh and the distribution of seals, other than a drop in offshore waters as compared to inshore coastal waters (Scott and Martin, 1959).

A number of other fishes were likewise infected, particularly the smelt, the American plaice, and the sea raven. No case of herring infection was found. Two other nematodes were frequently encountered (Templeman *et al.*, 1957). *Porrocaecum* larvae have been reported from the European side of the Atlantic by Kahl (1939), and in both Greenland and the Barents Sea by Grainger (1959)—in all cases occurring in the flesh. Besides cod, he found larvae in the flesh of ling, redfish, angler, and wolf-fish. The occurrence of nematode worms in cod has been reviewed by Dollfus (1953). Another species, *Anacanthocheilus*, was in addition encountered in cod fillets from Iceland, Bear Island, and the Barents Sea. Punt (1941) studied nematode parasites in many North Sea fish.

The incidence of infection and the number of nematodes per fillet usually is related directly to the size of the cod (Scott and Martin, 1957). The cod may become infected throughout its entire life, but the highest rate of infection occurs in small-sized cod. Changes in feeding habits which accompany growth in the size of cod may explain the fact that young cod frequently appear to be more exposed to infection than large specimens. Seasonal variations in the incidence of nematodes in different fishing locations are attributed to seasonal migrations of the cod. More intensive catching in certain shallow inshore waters is considered to account for a higher incidence of nematodes in this period (Scott and Martin, 1957).

The nematode *Contracoecum aduncum* is harassing the Baltic cod (for further references, see Schulman, 1959). The larvae infest the liver and greatly reduce its economic value. Regional differences prevail, too. Thus, the degree of infestation explains why the ratio of liver weight to total live weight is 4.5 times higher in Riga Bay as compared to the waters of Liban (Schulman, 1959).

D. Copepods

The brachiurian *Argulus* (often classified as a copepod) is a common parasite on the integument of many fish and elasmobranchs. At times, the incidence of infecting brachiurians may be great enough to produce open lesions on the fish. Usually the parasite irritates the epithelium layers of the fish, and may cause the fish to swim in an erratic fashion attempting to brush the parasite off.

Copepods are common inhabitants of the gills and surfaces of marine fishes. Walford (1958) gives the history of *Lernaeocera branchialis*, which begins its life as a free-swimming form and later assumes the role of a parasite in the gill covers of flounders. Leaving the flounder, as a free-swimming form again, it next takes a cod as its host. In the cod gills the organism loses its copepod appearance and develops into a mass of tissue which eats its way into the host tissues. In Cuxhaven, up to 20% of the codfish examined were infected and below normal in weight.

The parasitic copepod *Lepeophtheirus salmonis* is widely distributed as a sea louse on salmonids along the North Atlantic coasts, of both Europe and America, as well as in the North Pacific. Very heavy infestations have been discovered on the southeast coast of Nova Scotia (White, 1942), even to the extent of killing the fish (White, 1940). The skin in the occipital region was removed through these parasitic attacks, thus exposing the underlying red flesh. This species is marine and succumbs gradually when the fish enters fresh water for spawning. Species of the parasitic genus *Pennella* parasitize widely different hosts such as cetacea, flying fish, and swordfish (Gnanamuthu, 1951).

Several major fishing areas have been scanned with regard to the incidence of parasitic copepods: off Angola, by Nuñes-Ruivo (1956); off Madras in India, by Gnanamuthu (1951), Subhapradha (1951).

VIII. Atypical Cell Growth

Tumors and atypical cell growths frequently occur in marine fish (Nigrelli, 1953). Often aquarium fish will be found with tumors (fibromas) or growths on the head which are presumed due to traumatic injury from the aquarium walls. Certain cell hypertrophy may be caused by fungi, viruses such as lymphocystis, and microsporidians such as the encystment of *Glugea hertwigi* in smelt. Thyroid tumors have been reported for marine fishes in aquaria and in the natural habitat (Nigrelli, 1952). The thyroid tumors were malignant, infiltrating and destroying gill tissue, cartilage, and bone of the hyoid-mandibular-branchial complex. Epidermal fin tumors have been reported in the gobiid fishes (Tavolga, 1951).

In 1945–1947, an extensive epidemic of tumor disease, frequently named the "cauliflower" disease, in the silver and golden eel was reported in the area between the West Baltic Sea and the Kattegat along the German, Polish, and Scandinavian coasts (Christiansen and Jensen, 1947). New epidemics were reported in 1956 (Engelbrecht, 1958). The growth, consisting of epithelial tumors of a papillomatous structure, were primarily found on the head. Occasionally they appear on the fins or other parts of the body. Attempts to transmit the disease to healthy fish failed. This disease is also reported in cod (Schäperclaus, 1953). Whether it is due to a virus or initiated by a chemical traumatic effect is still an open question. The disposal of large quantities of mustard gases has taken place in these areas.

IX. Therapy of Marine Fish Diseases

The question of therapy of marine fish diseases raises special problems. It is quite impossible to control a naturally occurring disease due to environmental conditions. Thus, therapy must be confined to the aquarium or fish hatchery.

Unfortunately, most of the reports for the control of fish diseases are confined to fresh-water fishes, and it is difficult to extrapolate such treatment to the marine environment. Materials injected for internal therapy will not be affected by sea water. However, the pH and presence of salts may affect water therapy. For example, aureomycin loses its antibiotic effect in sea water of pH 8.2. Therefore, the extrapolation of fresh-water disease therapy to the marine environment should be made with caution.

Various types of bactericides, sulfonamides, antibiotics, dyes, and copper sulfate have been employed for the control of disease in fresh- and sea-water aquaria. In general, the bacterial diseases are best controlled with antibiotics or sulfonamides. The microorganisms causing tail rot and *P. ichthyodermis* can usually be controlled with a mixture of penicillin and streptomycin injected into the fish at the concentration recommended per unit weight. External lesions may be controlled with direct application of merthiolate or other bactericides. Furunculosis may be controlled with aureomycin or terramycin. Vibrio infections respond to sulfonamide therapy.

Davis (1956), in his book "Culture and Diseases of Game Fishes," adequately covers the therapy of most fresh-water fish diseases. It is imperative to note that the first steps in the therapy of aquarium diseases is to properly prohibit the spread of the disease by controlling the water which may pass through diseased areas, to sterilize periodically the aquaria walls with chlorine solutions, and to keep residue foods from decaying in the tanks. Experience has also shown that fish lose their resistance to disease when subjected to abnormal temperatures, pH or adverse water conditions. Many fish diseases are more prevalent during the warm summer months, and precautions should be taken to maintain a lower temperature in the aquarium during the summer.

An important factor in the cultivation of marine fish is to make certain that food is not contaminated with disease organisms. Often freshly caught or frozen marine fishes are used as food for aquaria fishes. Inspections of the food fishes should be undertaken to ascertain whether infections are present.

The larger external parasites and some external sporozoans such as *Eimeria* may be partially controlled by placing the fish in fresh water. Solutions of copper sulfate from 0.1 to 0.5 p.p.m., have been used to control *Oodinium*. External lesions may respond to treatment with mercurochrome or other germicides applied directly. Acriflavine was found nontoxic to killifish and was effective against protozoan infections at 10-hr. exposures of 10 p.p.m. of the dye (Pickford, 1952).

X. General Relationships

A. Disease versus Catastrophes

It is rather difficult to discuss fish diseases without a definition of the term. In man, the term "disease" encompasses a multitude of complex reactions of the human body to environment from malnutrition to virus infections. Thus, one must define what fish disease is and how it affects a living population of fish.

Mass mortality of fish in the marine environment is commonplace. If the mass mortality is caused by disease, it is called an epidemic, whereas other mortalities may be considered as catastrophes. The toxicity of *Gymnodinium* and *Gonyaulax* red tides to fish has long been known (Galtsoff, 1954). Although fish are sensitive to adverse salinities and temperatures and can often avoid such conditions, often mass catastrophes caused by abnormal environmental conditions are found along the coasts of the continents. Such mortalities are of interest to the paleontologist, who finds the remains of large masses of fish fossils in the geological record. Catastrophes may be caused by volcanism, abrupt salinity change, freezing, sudden change of temperature, toxins from microorganisms, lack of oxygen, or production of noxious gases such as H_2S, and stranding on beaches due either to severe storms or to pursuit by predators (Brongersma-Sanders, 1957). Even the effects of currents which carry fish eggs and larvae into adverse conditions may, in broad terms, be considered as a mass mortality.

B. Effect of Disease on Fish Abundance

One can only guess at the gross effect fish diseases have on the abundance of fish in the sea. Within the writer's experience, pandemics or large-scale epidemics of fish have never been reported. Several reports have been made describing localized epidemics.

It is unlikely that disease is a primary factor in maintaining an under-populated sea. The total population of the ocean may depend on the limiting concentration of some essential mineral such as phosphate, nitrate or vitamin B_{12} necessary to some part of the food chain. Thus, the death of a fish may not affect the long-range total population, because bacterial activities may release bound-up nutrients such as PO_4, NO_3, and other component minerals, or produce vitamin B_{12} during the decomposition activities. The by-products from the fish are then used by algae for the primary production of organic matter in the sequence of organic carbon cycles.

C. Man as Host to Fish Diseases

It is unique that most of the microorganisms pathogenic to fish are not pathogenic to man. Fish have been shown to harbor human pathogens, such as *Clostridium botulinum* type E., *Clostridium tetanus,* and *Erysipelothrix,* but the organisms are apparently not pathogenic to the host fish. Aronson (1926) reported the presence of tubercles in croakers, sea bass, and a sergeant major, and described the causative organism as *Mycobacterium marinum,* which was not pathogenic to rabbits or guinea pigs. Other organisms in sea water near sewage sources which might be pathogenic to man are *Escherichia,* which can be found in estuaries (Rittenberg *et al.*, 1958), paracolon bacteria, *Shigella,* and *Streptococcus.* Normally, human pathogens do not survive more than 2 weeks in sea water.

Lethal cases of *C. botulinum* type E toxin poisoning have reportedly been caused from the organisms in home-pickled herring and home-canned salmon (see Chapter 3, Volume II), Section IV on Botulinus poisonings for further reference). The origin of the microorganisms could not be established. *Clostridium botulinum* type E has been found in the intestinal contents of fish from the Sea of Azov. Type A strains of *C. botulinum* have been found in sea water. Therefore, it is possible that the lethal cases of botulinum may have originated when the fish were in the natural environment or soon after catching.

Erysipelothrix will grow quite readily in sea-water nutrient medium. Although the microorganism does no apparent damage to fish, fish handlers commonly contract the disease through fish-spine punctures or through cuts in the skin (Sheard and Dicks, 1949; Svenkerud *et al.*, 1951).

D. Disease in the Natural Environment

Usually, the microbiologist or physiologist is introduced to marine fish diseases when a specific incidence of an infected fish is brought to the laboratory, from reports of an extensive fish kill nearby, or from a fish which has died in an aquarium. Very rarely are references made to fish diseases discovered during the routine examination of fish on board a fishing vessel. The aqualung free-diving apparatus has provided some opportunity to observe fish in their natural habitat (Oppenheimer, 1953). More prevalent cases of infection have been noted on occasions. For instance, during several summers (1951–1953) fish with skin and eye lesions were common in the aquarium at the Scripps Institute of Oceanography. At the same time, Conrad Limbaugh during free diving operations reported the presence of similar types of infected fish in the waters outside the surf zone near Scripps and off the Coronado Islands, July, 1952 (personal communication). Limbaugh reported that from 5 to 10% of the fishes showed evidence of infection which appeared as white blotches on the sides or fins of the tail surfaces. Some of the fish were blinded in either one or both eyes by a coating of white material. Pike-perch, kelp bass, sheepshead, and blacksmith were identified. In September, 1955, Limbaugh further noted a mass mortality of the queenfish *Seriphus politus* under the pier of the Scripps Institute of Oceanography. From 20 to 40% of the fishes were infected with open lesions. The following day hundreds of dead queenfish were noted under the pier.

Many of the fish with lesions were inspected for the presence of pathogenic bacteria. Several pure cultures of marine bacteria, including *P. ichthyodermis,* were isolated which produced the characteristic lesions in inoculated fish.

Soviet investigations maintain that the composition of the parasitic fauna frequently distinguishes one race of a fish species from another. This is said to apply to local strains in the White Sea and to cod, herring, and "navaga" (Poljanskij and Byochovskij, 1959).

On the other hand, studies of the Baltic show that in the Finnish Bay and other less saline eastern parts are encountered a number of freshwater species of coccidia, nematodes, trematodes and copepodes, while in the western and southern more saline sections of the Baltic several typical Atlantic species of these same groups are found (Shulman, 1959). Engelbrecht (1958) investigated fish parasites in two areas off the German Baltic coast and concluded that fish in such brackish water are less subject to attack than either fresh- or salt-water fish. Two parasites are specific to brackish water and both the other two groups have difficulties in adapting to a brackish environment.

E. Detection of Diseased Fish

Often the lesions of fish are not noticed because of the physical properties of the refractive index of the water. In the water the lesions appear as cottony growths with perhaps an opaque membrane over the surface. When the fish is removed from the water, the lesion loses its characteristic appearance, and unless it is an open bleeding sore, the lesion may not be noticed. In the natural habitat it is difficult to get near enough to the fish to see that they are diseased. Also diseased fish may be ready prey for other fish and thus be noticeable only when large-scale infections are present.

The mortality of adult fishes and the incidence of pathogenic microorganisms has been reported in adult fish, yet we have to rely entirely on laboratory and hatchery rearing experiments and operations to obtain information on the mortality of eggs and larvae. The eggs and larvae of fish collected from the seas have been studied by many ichthyologists. Unfortunately, the small organisms must be collected by nets for examination and it is quite impossible to determine the difference between those which were dead in the water and those killed during collection. An experienced investigator can recognize larvae which are in an advanced state of decomposition, but possible microorganisms specifically responsible for death have usually been masked by the adventitious population of bacteria and other microorganisms which immediately attach to the dead eggs and larvae or are present in the plankton haul.

A large bacterial population may not be indicative of an abnormal incidence of diseases in the natural habitat. The shallow bays of the Texas coast and other similar bays may contain up to 100,000,000 bacteria per milliliter of sea water and yet harbor no increased incidence of disease.

One would expect that the eggs and larvae would be most susceptible to disease and that the survival of fish would depend on the relative survival of the young forms. Although aquaria research has demonstrated the apparent fragility and critical stages in the early development of fish, very little is known of their diseases. In large-scale hatching of cod, herring, and plaice in Norway, it has been noticed that the gas content and abrupt temperature change will adversely affect the survival of eggs and larvae (Dannevig and Dannevig, 1950). Bacteria and other unicellular organisms will also affect the survival of cod eggs. At the State Fish Hatchery in Arendal, Norway 2- to 3-month-old plaice and herring larvae were presumed killed by *Vibrio anguillarum* and the myxosporidia *Lentospora cerebralis* (Dannevig and Hansen, 1952).

It is within reason to assume that if the larger fish are attacked by pathogenic or parasitic microorganisms, the eggs and larvae will be similarly affected. It is possible that the vulnerable young forms are more susceptible to microbial attack than the adults. Thus the fluctuations in year classes may be, in part, due to the mortality of the young forms from microbial activities.

F. Fish Slime

Very little is known about the relation of slime or mucus excreted by fish to disease. Fish slime is a glycoprotein which is secreted by integument cells (van Oosten, 1957). It is assumed that different types of mucus are excreted by different fish according to the type of mucus-excreting cells.

Most investigators have found the slime of fishes to be a good source of food for bacteria and to provide a habitat for numerous species of bacteria which may vary seasonally (Gibbons, 1934). A primary protective mechanism of mucus has been described where the mucus is continually washed away during the movement of the fishes through water which in turn removes the bacteria before they can attack the skin. Large populations of bacteria cause the rapid decomposition of the fishes if they are not properly handled after being caught.

The mucus of some eels has a form of protective action by its ability to coagulate mud and particles in the water (van Oosten, 1957). It is possible that the fish can precipitate or coagulate bacteria and thus clear the water.

G. Control

In order to reduce the incidence of nematodes, spread by feces from seals to a number of important food fishes, it has been suggested that the seal be eradicated from vital fishing areas (Scott and Martin, 1957). Alternative measures are rated as ineffective.

Candling is employed to detect and remove parasites from cod fillets. In recent years this has become inevitable. Through this method only three-fourths of the infections are spotted. All minor attacks pass unobserved (Power, 1958).

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CHAPTER 16

Diseases of Fresh-Water Fish

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I. Introduction

Like other animals, fish can be subject to disease. From the viewpoint of fish as food, fish diseases are important for two main reasons: (1) the number of fish available for consumption is reduced; (2) the palatability of diseased fish may be impaired, or they may look unsightly, both conditions making them unacceptable for human consumption. Big economic losses may result from epidemics, especially if they occur in fish-breeding ponds. The protozoan *Ichthyophthirius multifiliis*, causing "white spot" disease, has a particularly bad reputation in this respect; it occurs all over the world.

Fish diseases may be due to parasitic or nonparasitic causes, the former being the most numerous and, from both a pathological and economic viewpoint, the most important.

II. Nonparasitic Affections

A. Disorders Due to Malnutrition

1. *Avitaminoses*

It has been demonstrated that for fish nutrition a number of vitamins, e.g. thiamine, riboflavin, pantothenic acid, inositol, folic acid, choline, biotin, and pyridoxine, are necessary (well reviewed by Halver, 1953). Vitamin requirements may vary among different species of fish and depend on environmental conditions. Although no definite conclusions could be obtained from feeding experiments with respect to vitamins K, B_{12}, and E, definite deficiency syndromes for these vitamins could be produced by treatments with the antibiotic Aureomycin, which affects the intestinal flora. Curiously, the related compound chloramphenicol (Chloromycetin) does not produce avitaminoses and is therefore preferred for treatment of bacterial infections in fish. If Aureomycin is incorporated in fish food, as is sometimes done in order to increase the growth rate, vitamins E, K, B_{12}, and folic acid should also be included in relatively large amounts.

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Avitaminoses may also play a role in infectious diseases by lowering the resistance to bacterial infections. Folic acid deficiency lowers resistance to myxobacterial infections, whereas lack of inositol and biotin increase susceptibility to fin rot and blue slime patch disease, respectively (Halver, 1953).

2. *Nonspecific Affections of Internal Organs*

Inflammation of the stomach, characterized by a reddening of the mucous lining, may result from excessive amounts of salt in the food. It may also be due to incorrect feeding. In fish breeding, it is more often observed in carnivorous fish, such as trout, than in omnivorous species (Schäperclaus, 1954). Healthy fish intestines are whitish or pink, making the red color a characteristic feature. Frequently a bloody, puslike liquid is present inside the inflamed intestine, and bloody or yellowish-colored slimy excreta are produced. Whether palatability of the fish will be impaired depends on the nature of the inappropriate food: tainted meat and rancid fats may contain substances that get into the flesh of the fish consuming such feed, thus spoiling its good taste for human consumption. Further conditions related to malnutrition are fatty degeneration of the internal organs, catarrh of the intestine, and its opposite, constipation.

As will be mentioned later, there is the possibility that a ravaging trout disease, causing liver degeneration and kidney swellings, should be classified as a deficiency disease (see Section III, C).

B. INTOXICATIONS

Many adverse conditions of a chemical nature can affect the health of fish. Extreme acidity or alkalinity of the water at first affects resistance to other diseases, but then exerts a direct specific action. The normal pH range differs greatly (pH 5.5–8); European waters generally have a pH 7–8, whereas in the tropics slightly acid reactions seem to be common.

Under aquarium conditions, it has been found that the breeding capacity of several species of fish depends on a suitable pH range of the water. Whereas lack of oxygen in crowded ponds may often cause heavy losses, the reverse condition of supersaturation with oxygen may also be dangerous by causing gas embolism. In running stream waters this will not occur. Carbon dioxide poisoning can occur only at rather low pH values and is not related to conditions of lack of oxygen, as shown by Van Duijn (1952), thus contradicting assertions by Atz (1950) and Klee (1951).

Many industrial waste disposals contain heavy fish poisons, such as phenolic and chlorine compounds, arsenicals, and heavy metal compounds, which are a real threat to fish population in industrial countries like those of Western Europe.

Intoxications can, however, result also from poisonous substances produced by metabolic processes. Among them must be mentioned ammonia, sulfuretted hydrogen, and nitrites, all of which result from microbial breakdown of proteins and may exceed critical concentrations if anaerobic conditions become prevalent in the water bottom; under normal aerobiosis the substances are converted into nontoxic compounds. Some microorganisms, such as certain unicellular algae, may produce substances toxic to fish. The palatibility of the fish may be affected by such substances and also by several other compounds that in themselves cannot be regarded as toxic, such as certain highly unsaturated fatty acids, present in blue-green algae (*Oscillatoria*).

Cases are also known where through a waterbloom, ammonia is released from an excess of available ammonium salts, thus reaching toxic concentrations, with a mass death of fish ensuing. This is reported from Germany, where sewage-treatment plants have released water with a high mineral content (Schäperclaus, 1952-1953). *Chlorella* and *Ankistrodesmus* are main constituents of such blooms.

C. Tumors

Several types of benign, as well as malignant, tumors occur in fish. Some are listed below:

adenoma
carcinoma
epithelioma
fibroma
fibrosarcoma
granuloma
hæmatoma
leiomyoma
lipoma
lymphosarcoma
melanoma
myxoma
neurilemmoma
neurofibroma
rhabdomyoma
teratoma

Numerous reviews of tumors observed in fish are available (Hofer, 1904; Plehn, 1924; Schlumberger and Lucke, 1948; Nigrelli, 1953; Schäperclaus, 1954b). A comprehensive treatise was also published in 1954-1955 by Reichenbach-Klinke.

While carcinomas are not uncommon in fish, sarcomas seem to occur but rarely; a true spindle-cell sarcoma has been reported by Van Duijn (1957). Tumors have no other effect than rendering food fish unsightly and less palatable. Since tumors occur only in isolated cases and in single specimens, their economic importance is minor.

A new disease in eels was reported for the first time in 1948 in the southern Baltic and has been given the descriptive designation of "cauliflower disease." Its syndrome and causative relationships are discussed in Chapter 15 of this volume.

III. Diseases of Parasitic Origin

A. FUNGUS INFECTIONS (MYCOSES)

Molds of the family Saprolegniaceae may attack the skin, and sometimes the gills and eyes, of fish in which the resistance of these organs has been weakened by injury, by other parasites, or such adverse conditions as an abnormal pH of the water. The infection is characterized by the growth of thin threads of dirty-white or grayish color from the infected parts, resembling tufts of cotton wool if growth of hyphae is abundant. Valuable fish can be cured by suitable treatments with chemicals; phenoxethol and some of its derivatives, introduced by Ian M. Rankin, at present may be regarded as the most suitable remedies. For a discussion of alternative treatments, reference is made to Van Duijn (1956).

While the Saprolegniaceae are mainly secondary invaders, other fungi are encountered which are much more dangerous. *Branchiomyces sanguinis* Plehn and *B. demigrans* Wundsch, belonging to the Phycomycetes —subclass Archimycetes—cause gill rot and may readily kill fish. High temperatures and the presence of much decaying organic matter in the water are conducive to the development of these infections. This disease is a major trouble in the carp hatcheries of the Ukraine (Dogel, 1957).

To the same subclass of fungi belong the *Ichthyophonus* parasites *I. hoferi, I. intestinalis,* and *I. lotae* (family Chytridiaceae, order Chytridiales). In living fish, symptoms are not distinctive: infected fish swim with sluggish movements, their bellies grow thin and show a concave contour. Finally, the fishes lose equilibrium and sometimes, if the parasites have penetrated into the brain, they make tumbling movements before they die. The parasites are found in internal organs, where they produce whitish-gray granular cysts located between tissues, or yellowish-to-brown, and even black-colored, cysts inside these organs themselves. These cysts may develop an amoeboid stage which periodically moves out and further penetrates additional organs. Generally, the course of the disease is slow; it may take months or even years before an infected fish dies. Infection takes place by transmission of cysts which, after having entered the water, are eaten by other fish. Infected fish are unpalatable, but they are no threat to human health if consumed. Extensive discussions on this important disease have been presented by Reichenbach-Klinke (1954), who proposed a change of the generic name, and by Schäperclaus (1954b).

B. Bacterial Infections

Most of the bacteria infecting fish can harm these only if they are injured or weakened. Occasionally, bacteria possessing a higher degree of pathogenicity may attack completely healthy fishes. With regard to the identification and nomenclature of bacteria pathogenic to fish, considerable confusion exists. This is due partially to deficiencies in the descriptions of bacteria isolated from diseased fish. On the other hand, there is some difficulty in obtaining reliable experimental material from animals that are surrounded by a medium in which all kinds of bacteria closely related to pathogens are present. Furthermore, experimental animals—required for proving the pathogenicity of an isolated strain of bacteria—cannot be kept under aseptic conditions. Consequently, knowledge is still scanty and often controversial.

Among the infectious diseases of which the bacterial ætiology seems to be well established are the following:

Furunculosis of salmonids is caused by *Aeromonas* (formerly *Bacterium*) *salmonicida.* Symptoms are heavy inflammation of the intestine and sometimes of the peritoneum, followed by hæmorrhages in the muscles and the production of swellings or boils (furuncles) at the surface, usually on the sides of the body. The disease is highly contagious and requires special measures for control. Sulfonamides, chloramphenicol, (Chloromycetin) and oxytetracycline (Terramycin) have been found effective (see review by Snieszko, 1953; also see McCraw, 1952).

Red pest of carp and tench (Latin: *Purpura cyprinorum*) is characterized by a red coloration of the skin of the belly and of the fins, while necrosis and hæmorrhages occur in the gills. Causative organisms may be special strains of *Pseudomonas putida,* sometimes distinguished as *forma cyprinicida* (formerly *Bacterium cyprinicida* Plehn) and *Pseudomonas putida forma* Davidi, and in addition *Pseudomonas plehniae.*

Red pest of eels (Latin: *Pestis rubra anguillarum*) is caused by *Vibrio anguillarum.* It also infects perch and pike, in which scale protrusion may be one of the symptoms. It occurs, however, only in waters with a relatively high salt content, at least 0.25%. The mortality rate from this disease is heavy. It is recorded that 200 years ago it occurred in the old and famous eel-rearing establishment at Comacchis, not far from Ravenna. Since then it has appeared on the Dalmatian coast, also on the Baltic coast of Denmark and Sweden, and in reservoirs on the Danish coast (Rushton, 1957). This disease was thoroughly investigated by an Italian biologist, Inghilleri, as early as 1901, and its ætiology clarified then.

Special strains of ordinary water bacteria may have pathogenic effects on fish. Among them is *Pseudomonas fluorescens,* which has been isolated as the causative agent of red pest and ulcerating diseases in eels and other fish (Schäperclaus, 1926). An epidemic caused by this organism, restricted to labyrinth fishes in a mixed population, has been described by Van Duijn (1938, 1956). Special strains of *Aeromonas* (formerly *Pseudomonas* or *Chromobacterium*) *punctata* have proven pathogenic to fish. Their importance has been especially stressed by Schäperclaus (1930, 1934), who also tried to identify numerous other bacteria described previously with his isolations. With regard to modern knowledge of bacterial variability and genetics, it must be considered doubtful whether distinguishing such strains as special separate varieties (*forma ascitae, f. sacrowiensis, f. pellis,* and even more) could reasonably be maintained.

Other strains of *A. punctata* have been isolated from several diseases in which ulcers and botches are produced. The pathogenicity of several strains of this species has been established experimentally.

An example of the considerable confusion as to the identity of bacteria isolated from diseased fish is the fact that whereas Schäperclaus (1930, 1954a) tried to identify every possible isolation with *Pseudomonas punctata,* Snieszko (cited by Griffin, 1953) advocates combining *Pseudomonas punctata, P. hydrophila, P. granulata, P. hirudinis, Proteus hydrophilus, P. melanovogenes, Aerobacter liquefaciens,* and others, all into one species which he named *Aeromonas liquefaciens.* Since in this list there are bacteria which have only slight sugar-fermenting powers and may show fluorescence (*P. granulata*), this combination does not seem justified, except perhaps for a few individual cases. At least the "Proteus" species have been wrongly named, since these have polar flagellation, as in the *Pseudomonas—Aeromonas* group, instead of a peritrich one, characteristic of the genus *Proteus.* In Soviet publications this very same organism is given the name *Achromobacter punctatum.*

The infectious swelling of the belly (ascites) is undoubtedly the most serious disease hampering present-day carp cultivation on the European continent, chiefly in the Soviet Union, Poland, and Germany. This disease is frequently termed "dropsy." In spite of a tremendous amount of research, and numerous devices and chemicals with which to combat this disease, it still is raging and constantly causing substantial losses. Various subtypes have been described, but Schäperclaus considers all of them induced by *A. punctata.* In recent years, the thought has become more prevalent that this organism could be a secondary invader only. Certain evidence points to the possibility that the primary infection is of a viral nature—see further Roegner-Aust and Schleich (1951) and Roegner-Aust (1952). This is strongly advocated by Soviet and Rumanian fish pathologists, while Polish studies support the bacterial concept of this disease (Kocylowski, 1958). Flemming (1958) reports that carp when starved, which frequently happens after the winter period, have a sharply reduced protein level in the blood and are particularly susceptible to dropsy attacks. Comprehensive reviews of all aspects of this important disease were published in 1953 by Wunder and Dombrowski and in 1959 by Gontjarov.

Schäperclaus (1954a) published substantial evidence for the existence of specific bacteriophages active against dropsy. By building up active phages in natural waters, it appears possible to check this disease.

Examples of bacteria representing other groups are *Haemophilus piscium,* isolated from intestinal wounds, blood, and kidneys of fingerling brook trout suffering from "ulcer disease," and some acid-fast bacteria causing fish tuberculosis.

Mycobacterium piscium and *M. platypoecilus* have been isolated from fresh-water fishes, and *M. marinum* from marine fish. They produce tiny knots (cysts) in the internal organs and may also affect the skin, fins, eyes, and skeleton. Fish tuberculosis may occur as epidemics and cause heavy losses. The causative bacteria are harmless to warm-blooded animals and man [see review by Reichenbach-Klinke (1954-1955) and also Van Duijn (1961)].

One noteworthy case of tuberculosis in salmon was reported in 1958 (Wood and Ordal) from the North Pacific region of the United States. Extremely high incidences were encountered in salmon known to be of hatchery origin—in some cases attaining 100%. The disease was absent in the silver and chum salmon known to be the product of natural spawning. The most likely method of dissemination was considered to be the practice of feeding untreated salmon carcasses and viscera to young fish in hatcheries. Baker and Hagan (1942) showed that the ætiological agent of tuberculosis in the Mexican platyfish was highly pathogenic when offered in the feed. Once the disease becomes sufficiently advanced, the bacteria are readily transmitted in a crowded hatchery pond.

A myxobacterium, *Chondrococcus columnaris,* causes "cotton wool disease," sometimes wrongly referred to as "mouth fungus"; it attacks the mouth, skin, and gills. Another important complaint due to bacterial infection is tail- and finrot; although several isolations have been made, it is not yet possible to ascribe this condition to a single definite species.

For a more general orientation on bacterial infections and their control, one should consult Griffin (1953) and Snieszko (1953).

C. Virus Infections

Thus far, only a limited number of fish diseases could be attributed to virus agents. It may, however, be expected that their number will increase markedly as soon as expert virologists become more interested in the field of fish disease. The most recent review is that by Watson in 1953.

Pox disease—Latin name: *Epithelioma papulosum*—is characterized by the occurrence of whitish, opaque spots on a thickened epidermis. It occurs mainly in common carp and Prussian carp, but has also been observed in other fish, including some outside the Cyprinid family, such as smelt and the European pike perch (*Lucioperca sandra*).

A new trout disease which has become a serious problem in the 1950's and is somewhat of a riddle is characterized by a swelling of the kidneys and a degeneration of the liver. It has been given numerous names—INuL (an abbreviation of the German description of the disease), Egtved disease (Danish designation), etc. Two schools of thought have developed as to the character of the disease, one maintaining it is an infectious virus disease, the other group that it is due to nutritional deficiencies (lack of vitamins B and E). Some research workers take the middle way and acknowledge the possibility that nutritional disorders reduce the resistance to infection and that infection increases the need for certain nutrients (Faktorovich, 1959). A comprehensive review of these controversies and the present knowledge on this matter recently became available (Mattheis, 1960).

Of considerable interest is the recent West German announcement that the Lake Research Institute in Langenargen succeeded in measuring the size of the responsible virus (Annual Report, 1959).

Infectious dropsy may be caused by a primary virus infection, generally complicated by secondary invasion of *Aeromonas punctata* or *Pseudomonas granulata* (Brunner and Striegel, 1952), or perhaps caused by these bacteria alone, as advocated by Schäperclaus (1930, 1954b).

D. Unicellular Algae

Some dinoflagellates may cause epidemical infections in fish. *Oodinium limneticum* is the causative organism of the velvet, rust, or gold-dust disease, in which the skin of the fish looks like a surface dusted with powdered sulfur or with talcum powder of a dark shade. The "dust" shows a pale yellowish color. It may move around on the skin surface. The infection may also spread to the gills. A related species, *O. ocellatum*

Brown (*Branchiophilis maris* Schäperclaus) attacks the gills of coral fishes (marine).

Chlorochytrium pisciolens, belonging to the Protococcaceae, may cause inflammations of the epithelium of the skin and the gills in carp, tench, and lake perch.

Other unicellular algae affecting fish are *Ichthyochytrium vulgare* and *Mucophilus cyprini;* formerly these were regarded as members of the *Chytridiaceae* (class Phycomycetes) of the fungi.

E. PROTOZOA

1. *Ciliata*

The most important parasite from this group is, no doubt, *Ichthyophthirius multifiliis,* causing white spot disease or "Ich." The causative organism is nearly sphere-shaped, holotrich, and contains a horseshoe-shaped nucleus. The parasite penetrates into the epidermis, which reacts by augmentation of the epithelial cells so that the latter is covered by a layer of tissue, appearing as white spots. Periodically, ripe parasites leave the fish for reproduction inside a cyst, where one parasite produces from 500 to 1200 young, which swarm out into the water; thus, infection spreads rapidly. Heavy losses may result from this disease. The biology of this parasite has been studied extensively by Buschkiel (1936). In the postwar period, the greatest losses in Soviet fish cultivation, particularly that of carp and trout, were inflicted through this ciliate (Bauer, 1958b). Owing to these circumstances this invading disease has been subject to extensive research (Bauer, 1958b). Most fishes gradually develop immunity. For a survey of treatments, one is referred to Van Duijn (1956) and Bauer (1958a, b). Through preventive measures and the use of curing chemicals, great improvements have been attained in both White Russia and other parts of the Soviet Union, and the disease is receding (Bauer, 1958a, b).

Chilodonella (formerly *Chilodon*) *cyprini* and *C. hexasticha,* belonging to the order Heterotricha, and *Cyclochaete domerguei,* of the order Peritricha, cause epidemics in which the symptom is sliminess of the skin.

2. *Mastigophora*

Costia necatrix (subclass Zoomastigina) causes sliminess of the skin, similar to that produced by *Chilodonella* or *Cyclochaete.*

Octomitus intestinalis and other *Octomitus* species occur as parasites in the intestine and/or the stomach and gall bladder of different fish. Symptoms consist of anomalous swimming behavior (staggering movement and spasmodic dippings of the anal fin) and emaciation resembling that occurring in *Ichthyophonus* infections. The parasites have an oval body with two groups of three short swimming flagella at the obtuse end and two longer steering flagella at the opposite end.

Sleeping sickness in fish is caused by several *Trypanoplasma* and *Trypanosoma* species, the former being the more common causative agents. *Trypanoplasma* differs from *Trypanosoma* in possessing two flagella situated at opposite ends of the body.

3. *Sporozoa*

A large number of infectious diseases in fish are caused by Sporozoa, most of them belonging to the subclass Neosporidia, order Cnidosporidia. A smaller number belong to the Telosporidia, order Coccidiomorpha. A survey is given by Van Duijn (1953, 1956); for an extensive treatment of this group, reference is made to Schäperclaus (1954b).

All sporozoa in fish are found in the internal organs, where many species produce cysts, which are often readily recognizable with the unaided eye as whitish knots. Sometimes "yellow bodies" are produced from necrotic tissue cells. These occur most abundantly in intestinal coccidiosis, where they are often accompanied by black pigment granules. In several sporozoan infections, knots, pimples, bumps, or boils are produced in the skin, the fins, and/or the gills. Some of the parasites found in knot or pimple disease (Latin name: *morbus nodulosus*) are *Myxobolus exiguus, M. dispar, M. oviformis, Glugea anomala,* and several *Henneguya* species. Knots at the gills are produced by several species of the genera *Myxobolus, Lentospora, Henneguya,* and *Thelohanellus.*

Myxobolus pfeifferi is the cause of boil disease in barbel. Boil diseases in Coregonidae and whitefish are produced by *Henneguya zschokkei, Myxobolus piriformis,* and *M. notatus. Glugea hertwigi* is the causative organism of a disease of smelt in which boils occur, not only in the skin, but also inside the body cavity.

One of the most important sporozoan diseases is the tumbling sickness of young trout (*Salmo fario, S. lacustris, S. irideus,* and related species), which is due to *Lentospora cerebralis.* This parasite occurs in the nervous system and the auditory organ, while they penetrate into the cartilage, too, thus preventing normal ossification and producing skeletal deformities. Affected fish lose their sense of balance and turn around in an awkward manner; while the position of the longitudinal axis of the body may be maintained, the body is turned around this axis over 180 or even 360 degrees some ten or twenty times before the fish is exhausted and takes some rest at the bottom of the water. This anomalous behavior occurs as sudden outbursts, alternating with periods of normal swimming. Tumbling movements first appear 40–60 days after the infection.

Diseased fish either die or heal spontaneously; in the latter case, they may remain crippled for life, or they may recover without external symptoms. In both cases they may remain carriers of living spores and spread the disease. Therefore, all such fish must be destroyed. Sanitation of infected ponds is performed by strewing 0.5–1 kg. of calcium cyanamide per square meter bottom area after draining off the water, to be added in two portions, the first at the end of November and the second half at the end of March. Six weeks after the second treatment the ponds may be filled again and put into use if the pH of the water is correct; otherwise, a change of water before setting fish may be required. This treatment was originated by E. Tack (1951) and is strongly recommended by Schäperclaus (1954b). The method is also valuable for disinfection in case of other infectious diseases.

F. METAZOA

1. *Crustacean Parasites*

All crustacean parasites of fish belong to the class Copepoda. The subclass Branchiura contains the well-known fish lice, *Argulus foliaceus, A. coregoni* Thorell (*A. phoxini* Leydig), and *A. pellucidus* Wagler (*A. viridis* Nettovich). These parasites have a flattened, leaflike shape and reach a length of 3 to 13 mm. A few specimens on a big fish do not do much harm, but sometimes they may appear in large numbers on one single fish. They are typical skin parasites and may also act as transmitters of bacterial infections from fish to fish. Thus, it has been experimentally established that the carp louse (*Argulus* spp.), if infected, conveys the dropsy agent to the host (Stammer, 1959-1960).

A large number of fish parasites are found in the subclass Eucopepoda. Members of the family Ergasilidae show some resemblance to the well-known fish food animal *Cyclops;* the parasitic genera are *Ergasilus* and *Thersitina.* They are mainly parasites of the gills, where they feed on epithelium and slime cells. Other gill parasites are found in the families Caligidae, which have a flat body, and Chondracanthidae, the latter still showing some morphological resemblance to the cyclopids. Further families of fish parasites are the Dichelestidae, Philichthyidae, Lernaeidae, Lernaeopodidae, and Sphyriidae.

The genus *Lamproglena* Nordmann 1832, is parasitic on the gills of various fresh-water fishes in Europe, Egypt, West Rhodesia, the Belgian Congo, French Sudan, the Soviet Union, Japan, China, and Thailand; it contains 16 recognized species (Humes, 1956). Best known are the parasites *Lernaea* (formerly *Lernaeocera*) *cyprinacea, L. esocina,* and *L. phoxinaceae,* occurring on and in the skin. They are often popularly called "anchor worms," which, of course, is biologically wrong, but at least gives a really good impression of the attachment organ and the slender, sausage-like shape of the body of the parasitizing females. Egg sacs are carried at the end of the body, as in Cyclops. Males do not parasitize fish. The females may reach a length of about 20 mm., not including appendages.

A review of parasitic Crustacea is given by Schäperclaus (1954b), while the old review by Hofer (1904) is still useful with some minor changes of nomenclature.

2. *Worm Infections*

Worms, which were once put together in one single phylum, are now distributed over a number of separate phylae of the animal kingdom. Some of these contain a large number of fish parasites.

a. PLATYHELMINTHES

Fish parasites are found in the classes Trematoda and Cestoda. Important external parasites of the Trematoda are found in the orders Digenea and Monogenea.

Yellow grubs are larval stages of the flukes *Clinostomum complanatum* or *C. marginatum*, belonging to the Digenea. They produce small, cream-colored, oval cysts on the body, head, and fins. The adult parasites live in the throat and mouth of bitterns, herons, or other fish-eating water birds. Eggs are deposited in the water with the excreta of the birds, where they hatch to miracidia. These infect water snails, where they change into sporocysts that produce rediae. The rediae form daughter rediae, which produce free-swimming cercariae which infect fish and develop into metacercariae. If the infected fish is eaten by a bird, the metacercariae develop into adult parasites and the cycle may start anew.

Black cysts in the skin are produced by the larvae of *Neodiplostomum cuticola* and related species. These have a life cycle similar to that of the yellow grubs.

In the same order a number of worms are found that in the adult stage live in the bile ducts and pancreatic ducts of cats, dogs, and human beings. The cat liver fluke *Opistorchis felineus* was found in all cats in the region of the Kurische Haff (Germany) in 1929, and in 1931 in some villages it was found in 6% of the inhabitants, as mentioned by Schäperclaus (1954b) (see also Chapter 1). It is very common in five major food fishes of the Dnieper, according to a recent study (Bliznjok, 1960). Opistorchiasis was encountered in 16% of 90 infected patients in a hospital in the upper reaches of the Irtysh River. The presence of the metacercariae of *O. felineus* was established in 55% of the ide, 49% of the whitefish, 45% of the roach, 41% of the tench, and 7% of the carp in Lake Faysan and that section of the Irtysh fed by this lake. All the patients were inhabitants of this area.

Getsevichynte (1958) recently made a renewed study in the lagoons of the Kurische Haff (Kurkij Zaliv), and could confirm the heavy worm infestation; no less than 129 species (49 trematodes, 16 cestodes, 10 nematodes, 4 acanthocephalids, etc.) were found in 424 fish.

The eggs of this worm are taken in by snails of the genus *Bithynia*, where they develop into cercariae that infect whitefish (*Leuciscus*) in which they live in the muscles. Human beings are infected if they eat such fish without proper heat treatment (cooking or frying). Related genera of these worms are *Haplorchis, Metorchis, Pseudoamphistomum,* and *Pachytrema.*

Fresh-water mullets are strongly incriminated as a vector for transferring various trematodes to man in Egypt (Fahmy and Selim, 1959-1960), as well as in China, the Philippines, and Hawaii (Martin, 1958). Most fresh-water fishes in the Lucknow region of northern India carry heavy infections of monogenetic trematodes on their gills (Jain, 1958). In Egypt, dogs acquire the infection primarily from the fish they are fed; man also is frequently infected (Fahmy and Selim, 1959-1960).

The eel seems to be immune to the trematode *Crepidostomum* spp., while brown trout is most susceptible. The parr is partially resistant. These are conclusions from recent studies in Welsh rivers (Thomas, 1958).

Flukes, not having such an intricate life cycle and living on the fish as adults, are found in the superfamily Gyrodactyloidae, and belong to the order Monogenea (the yellow grubs belong to the Digenea). The better-known genera are *Gyrodactylus,* mainly a skin parasite, and *Dactylogyrus, Neodactylogyrus,* and *Ancyrocephalus,* all three primarily infecting the gills and being dangerous. For a thorough treatment of their biology, the reader is referred to Dawes (1946). The most obvious symptoms are fading of colors, sliminess of the skin, folded fins, increased breathing frequency, with the gill coverings stretched open and the gills expanded and very pale. The degree of these symptoms varies with the main site of the infection. A sure diagnosis depends on microscopic examination of a smear of the slime from the skin and the gills.

Other Trematoda are parasitic in the internal organs of fish; most of these belong to the genus *Distomum* and have a life cycle including stages in mussels and snails.

Tapeworms (Cestoda) also have an intricate life cycle with change of hosts. They may be divided into three groups, one in which the larval stage occurs in a lower food animal eaten by the fish that is the final host, another in which the larvae live in the bellies of one species of fish and the adults in another one, which feeds on the former, and the third group comprising worms with a multiple change of hosts, the final one being a mammal. Common examples of the first group are the clove worm, *Caryophyllaeus laticeps,* with larvae in *Tubifex,* and *Proteocephalus* (*Ichthyotaenia*) species with larvae in *Daphnia* and *Cyclops;* further, the very large tapeworm *Ligula simplicissima* (specimens up to 7 feet in length have been found), whose larvae live in *Diaptomus.*

The most common representative of the second group is *Triaenophorus nodulosus.* The adult worms are most often found in pike, and the first larval stage lives in *Cyclops.*

From a hygienic point of view, the third group is the most important, since to this one belongs the dangerous tapeworm *Diphyllobothrium latum* (formerly *Dibothriocephalus* = *Bothriocephalus latus*). The adult worm may live in the human intestine, where it reaches an average length of 8 to 10 meters, while some specimens up to 17 meters long have been found. The eggs leave the human body with the fæces. If they enter any water, they develop into free-swimming, ciliated coracidium larvae. If these are eaten by a *Cyclops,* they develop into procercoid larvae of about 0.5 mm. maximum length. If the *Cyclops* is eaten by a fish, the procercoid develops into the last larval stage, the plerocercoid, situated in the interstitial space of the muscles or the liver and other intestinal organs of fish. The most common fish hosts in Europe are eel, northern pike, lake perch, burbot, lake trout, pope, or eelpout. The chars frequently convey this infestant; so does the grayling. In North America, it is found in the northern pike, walleye, sauger, yellow perch, and in the trout *Oncorhynchus perryi;* in Madagascar it occurs in the barbel.

The fish as such does not seem to suffer much from these parasites, which are mainly dormant until the fish is eaten by a human being. The latter is infected in case he fails to apply adequate heat treatment to the fish prior to consumption. In Western Europe this tapeworm seems to be nearly extinct now, owing to good hygiene, which prevents disposal of fæces in fishing waters, on the one hand, and better cooking habits, on the other. The chief center for *Diphyllobothrium* appears to be around the Gulf of Finland, where it is endemic. Southern Finland shows a prevalence of infection amounting to as much as 20% of the population (Gordon, 1959). A number of Soviet studies from lakes and rivers in adjacent areas, including the Baltic countries, have clearly established this. From these foci they move into the coastal regions of the Baltic Sea. With this ethnic group it has spread to regions chiefly inhabited by the Balts in the United States (Hugghins, 1959).

The fish tapeworm is not infrequently encountered in Alaska and

Greenland (Gordon, 1959). Babero (1951) stated that the incidence of infection was as high as 30% of the native Eskimo population in the Kuskokwim region of southwest Alaska. A new species, *D. alascense,* has recently been described from sledge dogs of the Eskimos (Rausch and Williamson, 1958). Since the natives and their dogs eat the same species of fishes raw, there remains the likelihood that they are harboring the same species.

Related species occur in other parts of the world, such as *D. cordetum* in Greenland and Iceland. Turkestan and Japan are among the countries where *Diphyllobothrium* infections still occur frequently. Occasionally the parasites develop in dogs and cats. Several wild animals, such as foxes, constitute reservoirs.

b. NEMATODA

Several nematodes live as internal parasites in fish. One such example is *Cucullanus elegans,* the larvae of which live in *Cyclops.* The adults, about 5 to 8 mm. long as males and 12 to 18 mm. as females, inhabit the intestines or the eyes. This worm is live-bearing. *Paramermis crassa* in its larval stage lives in red mosquito larvae. *Filaria sanguinea* is found in the fins of crucian carp. In large fish, nematode infections generally do not cause much harm, unless they become numerous. One such infectant is of some economic importance, the nematode *Cystoopsis acipenseris,* specialized on sturgeon (Saidov, 1954). Twelve per cent of *Lophiosilurus alexandri* from the Brazilian São Francisco River harbored nematodes and trematodes (Travassos, 1959).

c. ACANTHOCEPHALA

Parasites from this phylum (popularly called thorny-headed worms) in fish are typical occupants of the intestine. Generally, the larvae live in fresh-water shrimp (*Gammarus pulex*), the water louse (*Asellus aquaticus*), and related crustacea, or in insect larvae. In some species the fish is not the final host, but merely harbors the second larval stage, the final adult stage being reached inside some fish-eating warm-blooded animal. The characteristic feature of the *Acanthocephala* is their protrusible proboscis, bearing a large number of hooks. The body is not membered. The most important genera are *Echinorhynchus, Acanthocephalus, Corynosoma, Rhadinorhynchus,* and *Pomphorhynchus.* All are dangerous parasites, producing perforation of the intestines. No cures are known.

d. ANNELIDA

Parasites in this phylum are all found in the class *Hirudinea* (leeches). They are large external parasites with membered bodies and a large sucking disc at each end. The ordinary fish leech *Piscicola geometra* reaches a length of about 20 to 30 mm., about one inch on the average. Some other genera are *Pontobdella, Branchellion, Callobdella,* and *Cystobranchus.* Fish leeches feed on the blood of the fish and may cause considerable harm. They can also be dangerous as transmitters of *Trypanoplasma* and *Trypanosoma* species, which cause a sleeping sickness in fish, and of bacterial infections. Removal of leeches has to be done mechanically, by means of forceps (with blunt ends) after the leeches have been paralyzed by a 15-minute treatment with 2½% sodium chloride solution.

IV. Fish Parasites and Human Food Hygiene

In several countries, e.g., Denmark, Germany, Poland, the Soviet Union, Sweden, the United States, extensive surveys have been made of the occurrence of fish parasites. Particular attention has been devoted to commercially important fishes (Engelbrecht, 1958), such as pike, eel, pike perch, roach, tench, and bream. Detailed lists have been prepared of all categories of fish diseases. Figures could be quoted from all areas of the world indicating the types of infestation—in some regions very heavy and in other areas less. Nevertheless, parasites and diseases are reported from almost everywhere. An essential area of research refers to the transmission of parasites and diseases from one climatic area to another, frequently leading to mass spreading and a change in infective aggressiveness (Reichenbach-Klinke, 1955). This has been discussed in general ecological terms by Cameron (1950) and Szidat (1955-1957).

The most important question with respect to parasites occurring in human food of animal origin is, of course, whether these may threaten human health. With fish as food, the only parasites that are dangerous for man are the tapeworms of the genus *Diphyllobothrium,* and the liver flukes *Haplorchis, Opistorchis, Metorchis,* and related genera. *Diphyllobothrium* may cause heavy anæmia, attributed to some hæmolytic substance secreted by the worm and which may be resorbed by the human blood. If the infection is not recognized in time and anthelmintic treatment given, this anæmia may take a fatal course. Infection can be prevented completely if fresh fish is cooked or fried; grilling cannot be relied upon. General prevention lies in the public sphere; good sanitation will prevent the spread of human excreta without disinfection or other cleaning measures into free waters, and dogs and cats must be kept away from fish-breeding ponds.

Several of the red pest bacteria—earlier grouped together under the name of *Bacterium murisepticum* R. Koch—cause serious skin infections in man. They gain entrance through wounds or scratches and induce inflammations—erysipeloids. Fishermen and employees in fish establishments frequently suffer from this skin trouble (Bandt, 1952-1953).

Other infectious diseases of fish are of minor importance to human beings because they cannot be transmitted, as far as our present knowledge goes. Some may, however, affect human health in a general way by rendering fish unpalatable by enhancing putrefaction and other breakdown pressures. But in principle these defects are not fundamentally different from food spoilage in general.

Exploitation for fish farming encourages human settlements along rivers. This increases the degree of infections in the river, and in turn to a greater degree in the dammed reservoirs. Conditions develop that are particularly favorable for the spread of these infections among human beings according to Soviet studies (Izyumova, 1959).

V. Economic Importance

Few figures are available which assess the economic repercussions of fish diseases, although in fresh waters it is generally easier than in the ocean to obtain an idea of the scope of their ravages. In the artificial raising of fish, one should be able to arrive at concrete figures which closely estimate the losses. As fish cultivation is of major economic importance in few places, such appraisals are, however, not frequently made. It is, nevertheless, known that fish diseases constitute a very real and constant threat to hatcheries, fish-raising establishments, and artificial fish cultivation.

In the United States research on fish diseases is conducted in laboratories of the U.S. Fish and Wildlife Service, the Michigan Institute for Fisheries Research, the Washington State Department of Fisheries, and others.

In the United Kingdom some investigations of limited scope are carried out at certain government laboratories in England and Scotland. In the Netherlands there is no officially organized study of fresh-water fish diseases. Occasionally studies are undertaken by the Nederlandsche Heidemaatschappij, Arnhem. It is natural that the most intense work on diseases of fresh-water fish is done in European countries with valuable resources of rivers, lakes, and ponds.

West Germany is energetically pushing its fight against fish diseases, as well as conducting research in this area (Annual Report of German Fisheries, 1959). The Bavarian Biological Research Institute in Munich is particularly engaged in investigations of fish tuberculosis, and the spreading of new diseases through imported fish. The Institute for Lake Fisheries in Langenargen recently announced the isolation of the virus considered responsible for the kidney swelling of trout (Section III, C). The carp louse is particularly studied in the Pond Research Station in Erlangen.

The inland fisheries of East Germany have their scientific center in Berlin-Friedrichshafen, and a special branch for pond cultivation and fish diseases is located in Wismar. A special carp institute is operating in Königswartha.

In the Soviet Union four major fish research institutions devote a substantial part of their work to the diseases of fresh-water fishes. These are the All-Union Institute for Lake and River fisheries, Moscow (VNIORRCh), the All-Russian Institute for Pond Cultivation, Moscow (RNIPR), the Ukrainian Institute for Inland Fisheries (UNIRCh), and the Moscow Fisheries School (Mosrybwtus). A number of other academies, universities, and biological research centers are also active in this field. A thorough survey has been made to map the occurrence of fish diseases, and it is claimed that great advances have been made in combating these scourges. A comprehensive review of their accomplishments was published in 1958. A special scientific conference in this field was called by the Ichthyological Commission of the Soviet Academy of Science and held in Moscow in 1957. These proceedings were later published (Pavlovskij, 1958).

The Veterinary Institute at Pulawy in Poland is in charge of research and the diagnosis of, and prophylactic measures against, fish diseases. This center is, furthermore, provided with three special laboratories for fish diseases located in different regions of the country (Krakow, Olsztyn, and Wroclaw). The laboratory in Olsztyn, close to the Masurian marsh area, devotes its attention primarily to lake fisheries; the others serve chiefly fish-raising pond establishments (Kocylowski, 1958).

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CHAPTER 17

The Transportation of Live Fish

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I. Introduction

The major transporters of live fish are the various government agencies engaged in artificial propagation of game and commercial fish. The transporters of live food fish, notably those who carry carp, probably are still second in terms of weight of fish moved. In North America there is also a growing traffic in bait minnows and in the transport of various warm-water species and trout to ponds where they may be caught on a pay-as-you-fish basis. In terms of variety of species and distances shipped, the tropical fish industry stands first.

There are three general methods of transporting live fish. They may be shipped without any water at all under certain circumstances, except for being kept damp. The second method, which will be referred to as the "tank method," is to ship them in containers of various types open to the atmosphere. The third method, which may be called the "plastic-bag method," since these are so conveniently employed for the purpose, is to ship the fish in a closed container partly filled with water and with the air in the space over the water replaced by an atmosphere of pure oxygen.

There is a definite limit to the time that fish can be shipped out of water, but for very hardy species this can be a substantial period. On the West Coast of North America, the long-jawed mudsucker, *Gillichthys mirabilis,* is flown in moist moss from the lagoons of Mexico to California. The mummichog, *Fundulus heteroclitus,* of the Atlantic coast is also shipped for bait in a similar fashion. McDonald (1884) long ago demonstrated that carp would survive long periods of time in limited amounts of water. In recent years, various salmonids (Cuerrier, 1952; Loftus, personal communication) have been transported in crushed ice, or moss with ice, as have been northern pike and the yellow pike perch (Schultz, 1956). These fish were all relatively large, from one to several pounds in weight. They were immobilized by urethan or tricaine methane sulfonate and were packed much as fresh fish would be, although not so closely together. The safe time for such transport is of the order of 4 hr.

Trout eggs are ordinarily carried out of water on cloth trays and kept sufficiently moist and cool. A description of typical transport methods and equipment for trout eggs may be found in Davis (1953, pp. 41-42), and for salmon eggs in Burrows (1949).

Present-day fish-handling equipment employed for the tank method is of many types, varying from simple metal cans carried on mule back to complex tank trucks holding as much as 2000 gallons of water. The larger tank units are usually equipped with circulation systems powered by small gasoline engines or electric motors. The circulated water is run through venturi aerators and thence into the tank, or through spray nozzle systems into the water surface (Copeland, 1947; Horton, 1956). Turnover rates vary from about once in 6 min. to once in 20 to 30 min. In general, tanks with the higher turnover rates haul the greatest weights of fish per unit volume. This is almost certainly related to the efficiency of gas exchange and distribution of aerated water throughout the tank. Average loads for larger tankers are 1½ pounds of trout per gallon, while the heaviest loads may exceed 2 pounds per gallon, for nondrugged fish. For short journeys, as in planting fish by airplane, loads may be as high as 5 pounds per gallon (Prévost and Piché, 1939).

Several successful large tankers use diffuser aeration, employing carborundum airstones, or perforated loup aerators. Most such units employ compressed oxygen released through regulating valves (Greene, 1956). Some tankers use electric stirrers which draw a vortex of air into the tank water or disperse air through perforations along the heels of the stirrer blades (Stubblefield *et al.*, 1949). Modern German transporting tanks for live fish were given a detailed description by Krause (1957).

Water temperature in transport tanks is usually controlled with ice and tank insulation. Refrigeration units are bulky and are in use only on very large tankers.

Fish transport tanks are generally constructed of heavy planking, welded steel, aluminum, or marine plywood coated with plastic resin. Fish-holding equipment used in the marine bait industry or on board tuna-bait boats consists of large rectangular or oval wells with lighted hatches through which fresh sea water is continually pumped at rates varying from one turn-over in 6 min. to about one turn-over in 12 min. (Carlson, 1955).

Most fish-planting agencies hold fish without food for 24 hr. or more prior to loading, to prevent regurgitation of partially digested food material into the water during transport.

Transfer of fish into transportation equipment is accomplished by dip net, by bucket, or by rubber conveyor belts (Leitritz and Macklin, 1956). Planting trucks generally transfer fish from the truck to the stream or lake by means of large-diameter hoses or portable metal piping which discharge from the tank itself. Weights of fish per unit volume are generally determined by displacement.

Plastic-bag transport (Miller, 1956) first came into general use less than a decade ago. However, closed systems were employed prior to that time (Vaas, 1952), and glass or polyethylene carboys are still sometimes preferable to the relatively fragile polyethylene bags. The usual method of using plastic bags for shipping is to place two bags, one inside the other, in a cardboard box. This box is often insulated with slabs of glass wool or expanded cardboard. The desired amount of water, usually 5 gallons or less, is poured into the inner bag. The fish are introduced and the bag is partially inflated with oxygen and sealed with rubber bands. The box is then sealed and shipped to its destination by air. The primary advantages of the method are reduction in shipping weight and reduction of injury resulting from fish hitting container walls.

The problems which must be met in the successful transportation of live fish are many and diverse. The primary problem arises from the low capacity of water for oxygen together with its low capability to dissipate the end products of metabolism. The secondary problem is that of handling. In delicate species, abrasion needs only to be sufficient to remove the mucus from a fraction of the area of the skin in order to rob them of essential protection from osmotic stress. Many fish, too, are so stimulated by handling that they readily accumulate dangerous levels of lactic acid in their blood (Black, 1958). Excessive changes in temperature are also deleterious, as is well known. For a recent review on these crucial factors see Norris *et al.* (1960). The optimum number of fish to be transported in each tank is determined by the species (rate of respiration), fish size, general physiological and health condition of the fish, the water temperature in the transporting vessel, and the duration of the transport (Krause, 1957).

II. Requirements for Fish Respiration

The level of oxygen required is something more than the bare minimum that will prevent asphyxia in an undisturbed fish. Fish must at least perform compensatory movements throughout the journey. Furthermore, fish are easily stimulated to increase their oxygen consumption to near their maximum rates, and are slow to return to the resting level, so that the excitement of capture and transfer to the transport tanks is likely to increase greatly the need for oxygen. There is also the possibility that an initial severe struggle may lessen the ability of the blood to transport oxygen for some time afterward.

It is proposed here that a suitable physiological standard for the oxygen consumption of fish in transport is half the rate of respiration of which a fish is capable above the rate required strictly for maintenance in the resting state. To determine the rate required to meet this standard, two measurements of respiration are made, one with the fish forced to be active and the other with the fish quiescent. A general description of methods of making these measurements, together with other considerations on the respiration of fish, will be found in Fry (1957).

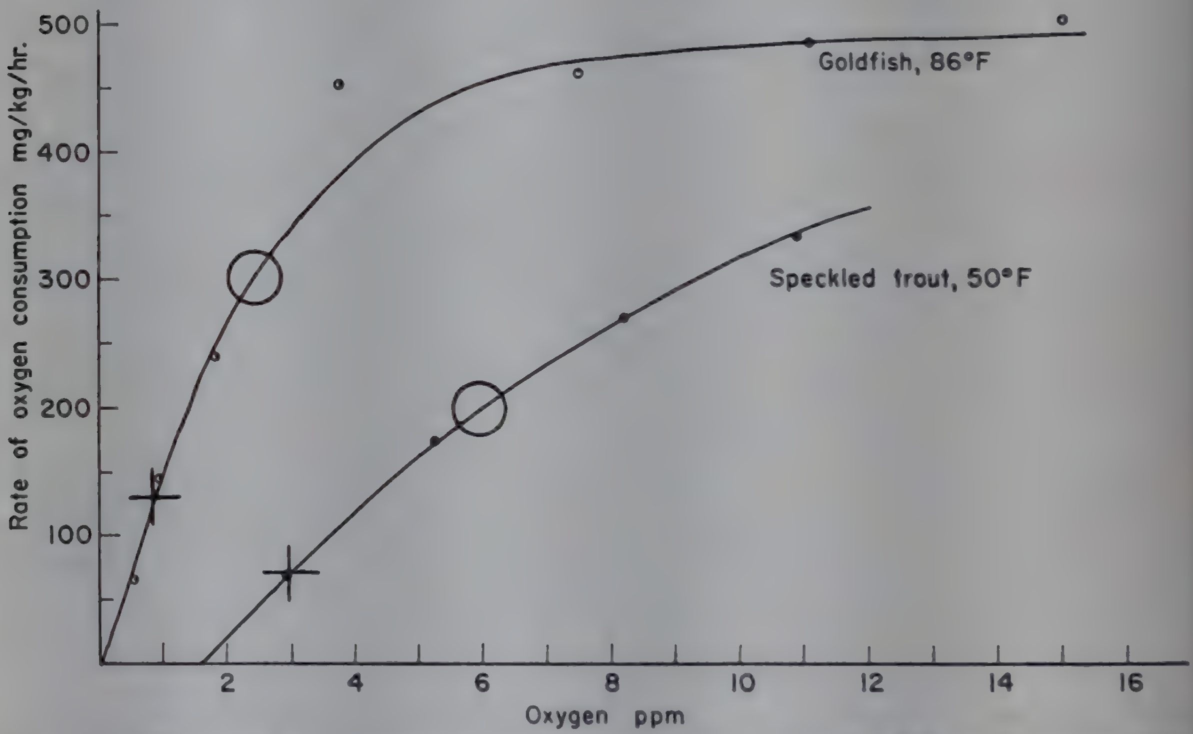

Fig. 1. The relation between oxygen consumption of active fish and concentration of dissolved oxygen. For explanation see text. Average weight of goldfish approximately 80 g., of speckled trout approximately 200 g. From Basu (1959).

Figure 1 illustrates examples of the respiratory requirements of two species of fish, one sensitive and the other insensitive with respect to oxygen lack. The curves show the respiration of the fish stimulated to activity. First, it may be seen that above a certain concentration of oxygen, the rate of oxygen consumption does not change with further increase in the external level of oxygen. If the stimulation of the fish has been adequate, it may be taken that the rate of oxygen consumption at these high levels will be the maximum steady rate of oxygen consumption of which the fish is capable. Second, it will be noted that at lower levels of oxygen concentration, the fish, though still stimulated to activity, will not consume oxygen at its maximum rate. At these lower levels of oxygen concentration, it is considered that the respiration of the fish is limited by the amount of oxygen in the water. Figure 1 illustrates these characteristics of the respiration of active fish for two species, one very sensitive to oxygen lack—the speckled trout—and one resistant species—the goldfish.

Each curve in Fig. 1 bears two symbols, a cross and a circle. In each, the cross indicates the resting metabolic rate of the fish (determined elsewhere by observations on undisturbed fish) and the level of oxygen required in the water to satisfy this rate. The levels thus indicated represent essentially the absolute minimum oxygen concentration required for undisturbed fish. The circles on the two respiration curves represent the rates of oxygen consumption which give the fish a margin over their resting rates of half the further amount that they can consume, together with the level of oxygen concentration which will permit the fish to meet this rate. In the example the half-scope rate of oxygen consumption of the oxygen-sensitive species, the speckled trout, is 200 ml./kg./hr. at 50°F. That for the oxygen-insensitive species, the goldfish, is 305 ml./kg./hr. at 86°F. Such rates of oxygen consumption will be termed "half-scope rates." The rates in the example would be met at oxygen concentrations of 6.0 p.p.m. in the case of the speckled trout and 2.6 p.p.m. for the goldfish. Such concentrations of oxygen which permit the half-scope rate of oxygen consumption to be met will be termed "half-scope levels."

Large individuals consume less oxygen per unit weight than do small ones. The general relation between oxygen consumption and size is $Y = bX^{0.8}$, where Y is the rate of oxygen consumption, X the body weight, and b is a constant appropriate to the species. The exponent varies from 0.6 to 1, but the extremes seem rare. With an exponent of 0.8 a tenfold increase in size of an individual will lead only to a little more than a sixfold increase in oxygen consumption. Conversely, this means that the total weight of fish carried in a given transport must be reduced to 60% of the capacity load for larger fish when the individuals are only one-tenth as large. The well-known Q_{10} rule whereby the rate doubles for a temperature rise of about 18°F. is a sufficient approximation for estimating the effect of temperature. This applies, of course, only within a species, for cold-water species consume approximately the same amount of oxygen at lower temperatures as do the warm-water species at higher ones. The half-scope level of oxygen concentration varies with species and temperature, but is relatively independent of size (Job, 1955). It rises with temperature, but not unduly so. In a later study on milkfish, Job (1957) revealed a proportionate rise in the metabolic rate at higher temperature

(29°C.). The relative increase in rate of oxygen consumption was greatest in small-sized fish.

For every milliliter of oxygen that a fish consumes, it will produce approximately 0.9 ml. of carbon dioxide. The fate of this gas will be to enter into the equilibrium system of carbonates, bicarbonates, and free carbon dioxide dissolved in the water. From the point of view of respiration, only the fraction that accumulates as free carbon dioxide needs to be considered. The effect of increase in free carbon dioxide is to depress the ability of active fish to take up oxygen as is illustrated in Fig. 2.

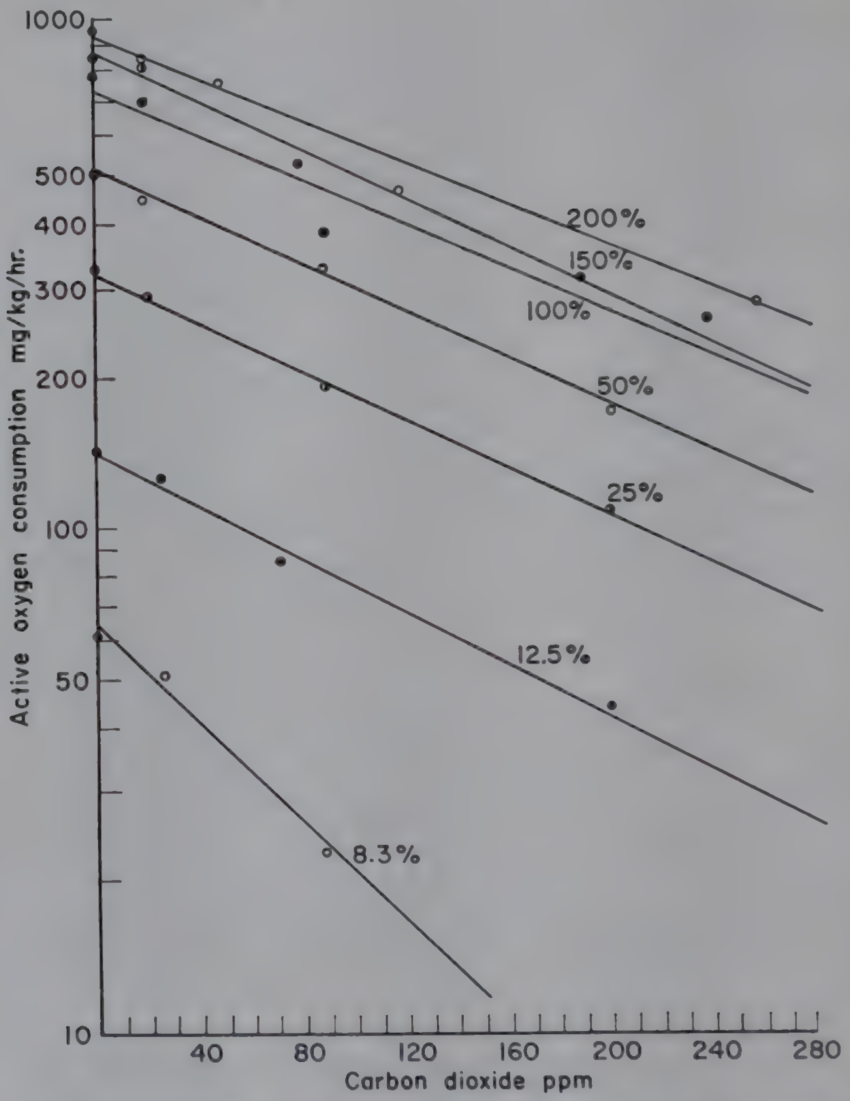

FIG. 2. The combined effects of various concentrations of dissolved oxygen and carbon dioxide on the oxygen consumption of active carp, *Cyprinus carpio*, at 86°F. Average weight of fish approximately 100 g. Each curve represents the data for a given level of oxygen in terms of per cent air saturation. From Basu (1959).

In addition to the direct effect on respiration, any excess of carbon dioxide over the amount required for equilibrium with the bases available will attack any unprotected metals. In particular, toxic quantities of zinc or copper may be dissolved from galvanized piping or containers or copper tubing (Affleck, 1952). The toxic effects of such metals may be delayed, and the fish may complete the journey in apparent safety only to die a day or so afterward. Zinc or copper should, therefore, not be contained in the material out of which the transport tanks or any equipment in contact with the water are manufactured.

Basu (1959) has calculated the various combinations of oxygen and carbon dioxide that permit several species to fill their half-scope needs, and his data for the two species taken here as examples are illustrated for different temperature levels in Fig. 3. It can be seen that an accumulation of free carbon dioxide up to 25 p.p.m. can be readily tolerated by a sensitive species under adequate aeration, and up to 50 p.p.m. by an insensitive one. It is also apparent that when the concentration of carbon dioxide considerably exceeds the limits mentioned above, the amount of oxygen is no longer important, since any reasonable increase will have no beneficial effect.

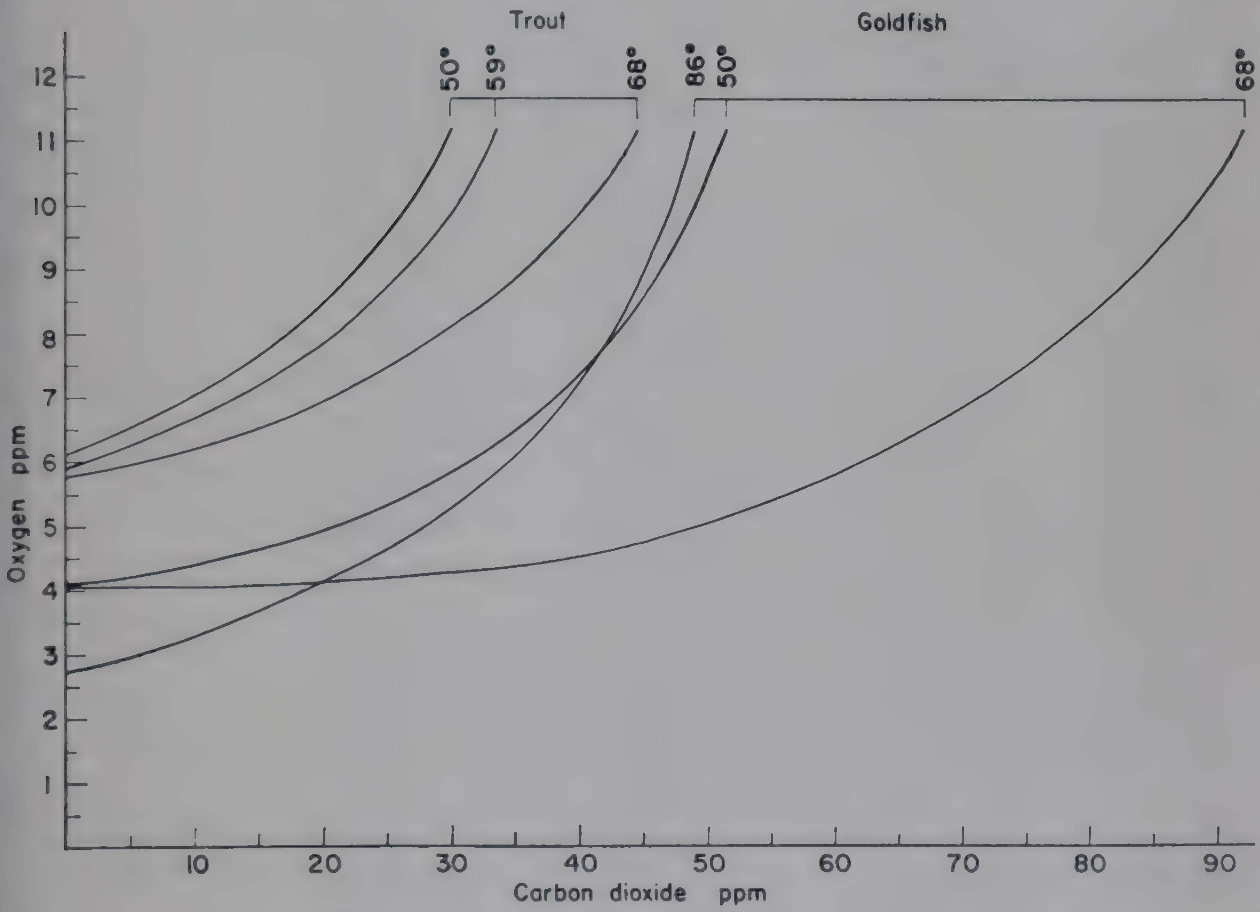

FIG. 3. Concentrations of carbon dioxide and oxygen that permit speckled trout and goldfish to consume oxygen at the half-scope rate at various temperatures. From Basu (1959).

It can be concluded that the need for aeration during transport is to provide oxygen at a rate and level that will fill the half-scope needs, together with means of keeping the concentration of carbon dioxide at a satisfactorily low level.

III. Accumulation of Ammonia

A large fraction, which for practical purposes here can be taken as half of the nitrogenous excretion of fish, is ammonia, which in the appropriate form ($NH_3.H_2O$, nonionic free ammonia or undissociated ammonium hydroxide) is a highly toxic substance (*cf.* Doudoroff and Katz, 1950). The fraction of the excreted ammonia which appears in the toxic form is markedly affected by the presence of acids in the water, as was emphasized by Wuhrman *et al.* (1947) and Wuhrman and Woker (1948). For example, at pH's of 7.5, 8.0, or 8.5 respectively, at approximately 60°F., a concentration of 0.5 p.p.m. of un-ionized ammonia (as NH_3) would be associated with 100, 17, or 5 p.p.m. ammonium nitrogen (as N) as ordinarily determined. A concentration of 0.5 p.p.m. approximates the 24-hr. median lethal dosage for rainbow trout at 68°F. in water half air-saturated with oxygen (Water Pollution Research, 1956). The precise quantity of un-ionized ammonia associated with a given pH varies with temperature, being higher at a higher temperature (Everett and Wynne-Jones, 1938). There is little effect of temperature on the sensitivity of a given species to a given level of un-ionized ammonia (Woker, 1949).

The rate of excretion of nitrogen is related to the rate of metabolism. Gerking (1955) found that the bluegill, *Lepomis macrochirus*, excreted about 7 mg. N per kilogram calorie of energy expended. As with other products of metabolism, large fish of a given species produce less per unit weight than do small ones. In addition, they are somewhat more resistant to the toxicity of ammonia (Wuhrman and Woker, 1950). Thus, at 78°F., Gerking found that 20-g. bluegills excreted nitrogen at a rate of approximately 500 mg./kg./day, whereas the rate for fish weighing 100 g. was only 120 mg./kg./day. The exponent relating weight to nitrogen excretion in the case of the bluegill above was slightly under 0.6, which may be exceptionally low in light of the general range of the exponents found relating oxygen consumption to weight. The rate of nitrogen excretion can also be expected to be dependent on temperature and to vary with different species. In aquarium experiments, Phillips and Brockway (1954) found that speckled trout weighing 16–30 g. and starved 15 hr. excreted approximately 115 mg./kg./day NH_3 at 51°F. At 31°F. the rate for these fish was reduced to 30 mg./kg./day. Tanizaki *et al.* (1957) report that at 59°F. rainbow trout weighing 60 g. excreted 150 mg./kg./day total N. These values, of course, do not apply to feeding fish. The longer fish are kept in a transporting vessel, the larger the oxygen demand of the water (as measured with $KMnO_4$), outside of the direct fish respiration. This presumably can be attributed to an accumulation of organic substances (Krause, 1957).

IV. Effects of Overexertion

Black (1958) has summarized the information on the effects of overexertion on fish. Death occurs in certain circumstances following severe muscular activity, such as struggling in a live box, vigorous avoidance of capture, and swimming against swift currents. The precise cause of death is not known; however, it is likely that the severe acid-base disturbance following the large accumulation of lactic acid may be the principal cause of death. The acid concentration is sufficient to reduce the acid-combining power of the blood, and its oxygen-carrying capacity must be profoundly affected as well. There appears also to be a marked reduction in the ability of the heart to pump blood following severe exercise. Severe muscular activity rapidly reduces the maximum swimming capacity of fish, and recovery is slow (6 hr. for adult steelhead trout; Paulik and DeLacy, 1957). Thus, fish planted in a fatigued state may be at a disadvantage aside from any deaths that may have resulted directly from overexertion. Hasler and Wisby (1958) report that most of a sample of largemouth bass taken on hook and line and released over deep water failed to home, while the majority of trap-netted fish were successful. Their explanation was that the failures were largely fish that were so fatigued that they could not swim to keep above the oxygen-poor depths over which they were released. Studies on fatigue to date have apparently all been carried out in well-aerated water. It is to be expected that under less ideal conditions the problem would be intensified.

V. Principles of Aeration

Because of its importance in fermentation and in waste disposal, the transfer of oxygen from gas to water has received a great deal of attention. Downing and Truesdale (1956) give an excellent elementary account of the principles involved, together with pertinent references. When water is sufficiently stirred so that the concentration of oxygen is essentially uniform throughout its volume, the rate of transfer of oxygen from gas to water can be expressed by Bohr's equation

$$\frac{dC}{dt} = K(C_s - C)$$

where C is the concentration of oxygen in the water at time t and C_s is the concentration of oxygen in equilibrium with the gas phase. The constant K is ordinarily termed the "specific rate of aeration." The best values for C_s are those of Truesdale *et al.* (1955), which may also be found in Mortimer (1956), Lagler (1956), and Hutchinson (1957). These values refer to saturation with air at sea level and should be multiplied by five when pure oxygen is used for aeration. The constant K can be expressed in terms of more fundamental constants by use of the expression

$$K = f\frac{A}{V}$$

in which A is the area of the gas-water interface and V is the total volume of water. Thus it can be seen that K is unique for each individual piece of equipment. In diffusion equipment, A is the area of the gas-water interface presented by all the bubbles in suspension at any given time and thus can only be approximated. With stirring, the surface will also be continuously varying and cannot be measured exactly. Even the constant f, which represents the rate of travel of the gas through the interface, fluctuates greatly, too. The great source of variation in f is the degree of turbulence of the water. It is advisable, as Haskell (1941) did, to make a determination of K for each given piece of equipment, using water in which fish have been respiring, since f is also influenced by contaminants. The values of f that will hold for transportation equipment will be of one of two orders of magnitude, being either in the range of 1–10 in the plastic-bag system or in the range of 50–100 for systems in which aeration is achieved by diffusion of air or oxygen or recirculation of the water through jets. The value of f will increase some 1–2% per degree Fahrenheit so that the rate of aeration at a given concentration of dissolved oxygen will tend to be independent of temperature, as Hutchinson (1957, p. 589) has pointed out. As follows from the relation of K to f, the area of the gas-water interface is of prime importance, the most efficient aeration being achieved when the gas is presented to the water in the greatest number of bubbles, or the water to the gas in the finest spray. Bowers (1955) gives a good account of the principles governing the size of bubbles formed by aerators. When gas is fed to any given diffuser beyond a certain critical rate, the bubbles issuing from it will coalesce, and the efficiency of the system will fall. (Diffusers, therefore, should have adequate capacity.) This principle is well illustrated by Haskell's (1941) data.

When air is diffused through water, the f values for the exchange of oxygen and carbon dioxide are the same (Water Pollution Research, 1955; see also Downing, 1958), and preliminary experiments indicate that the same holds true for aeration by stirring. Hence, the advantage with respect to the removal of carbon dioxide which the spray system has been considered to have, as opposed to bubbling air, does not appear to exist. However, if oxygen is used as the aeration gas instead of air, and is supplied only in sufficient quantity to satisfy the demands for that gas, it is not likely that the carbon dioxide will be cleared sufficiently rapidly. It follows that if f_{O_2} equals f_{CO_2} then, for example, a saturation deficit of 5 p.p.m. O_2 left by diffusing air when $C_{s(O_2)}$ equals 10 p.p.m. will lead to a carbon dioxide excess of about 6 p.p.m. over air saturation. But if oxygen were the diffusing gas and the same level of oxygen were maintained in the water, then the oxygen deficit would be 45 p.p.m., and the lesser gas flow which could then maintain the necessary influx of oxygen would permit the carbon dioxide to build up to 54 p.p.m. above air saturation with that gas. Haskell and Davies (1959) recognized this latter problem and recommended methods of purging the excess carbon dioxide including the addition of lime water. In the plastic-bag system, carbon dioxide will necessarily build up in the water, since any that diffuses out into the atmosphere above the water will be held there and reduce the excess pressure in the liquid phase. To counteract the accumulation of free carbon dioxide in such systems, McFarland and Norris (1958) have tested an organic buffer, tris(hydroxymethyl)aminomethane, as a transport agent and report a fiftyfold increase in buffering capacity at 20 g. per gallon with maximum hydrogen ion absorption between a pH of 7.5 and 8.5. Accumulation of free CO_2 is temporarily eliminated by this buffer. Inorganic buffers such as sodium monophosphate and sodium bicarbonate have been tested, with conflicting results (Vaas, 1952; Saha *et al.*, 1956).

Ammonia, although volatile, cannot be effectively kept below toxic levels by aeration (Water Pollution Research 1955, p. 35). However, it can be expected that it will be largely neutralized by the respiratory carbon dioxide (Alabaster and Herbert, 1954). Under conditions where the carbon dioxide is removed by means other than aeration or where for other reasons, such as a high ratio of fish to water, a dangerous increase of ammonia may be expected, it can be removed by ion-exchange resins (Nemoto, 1957; Saha *et al.*, 1956; Tanizaki *et al.*, 1957).

VI. The Use of Anesthetics

The use of anesthetics to reduce the metabolic rate of fish in transport has not been universally advantageous (Webb, 1958). To be effective, the anesthetic has to be carefully chosen and the dosage closely controlled. McFarland (1959; 1960) appears to have been the only worker who has done extensive fundamental work on this problem. He considers the most useful anesthetics for inducing quiescence during transport to be chloral hydrate, tertiary amyl alcohol, and methyl parafynol. Sodium amytal has the disadvantage of being affected by the calcium content of the water, and tricaine methane sulfonate tends to break down. Urethan, now largely discarded by most workers because of its potential danger as a carcinogen (Wood, 1956), also has the disadvantage of low potency.

The stage of anesthesia produced should not go beyond a sedation that depresses reactivity to external stimuli without loss of equilibrium. Thus, the dose must be carefully gaged. McFarland (1960) found the concentrations in grams per U.S. gallon tabulated below to give the desired effect in the California killifish and the opaleye.

Anesthetic	Concentration per gallon
Tertiary amyl alcohol	2 ml.
Methylparafynol (Dormison)	1.0–2.0 ml.
Chloral hydrate	3.0–3.5 g.

A twofold variation in dosage will usually take the stage of anesthesia beyond the desired limits. Smaller fish are more resistant to anesthetics than are larger ones. The rate of induction of anesthesia is hastened by higher temperatures, but there is little temperature effect on level.

McFarland (1960) emphasizes that the effect of anesthetics in their useful range of concentration is sedation, not the reduction of cellular metabolism. For example, stimulation of metabolism caused by feeding will not be suppressed.

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CHAPTER 18

Radioactivity and Seafood

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I. Introduction

X-rays and radium, mainly used for medicinal treatment, constituted the only important radiation hazard to man prior to 1945. With the subsequent vastly expanded use of radioactive material, primarily for military purposes and industry, not only has the potential radiation danger increased many times, but so has the danger from fallout. Oceans covering large proportions of the earth naturally are major recipients of man-induced stratospheric and atmospheric radionuclides. It therefore seems appropriate to survey to what degree such radioactive matter can enter the aquatic food harvests and if they might influence in any detrimental way the normal productivity of the oceans.

Radioactivity is measured in terms of the number of disintegrations per unit of time. The disintegration rate of radium has arbitrarily been selected as a standard. The unit is called *curie* and is defined as the quantity of any radioactive material having associated with it 3.7×10^{10} disintegrations per second (or 2.2×10^{12} disintegrations per minute). One gram of radium has an activity of one curie. Other radioisotopes disintegrate at different rates; therefore, the number of curies per gram varies from isotope to isotope in proportion to the half-life and the number of atoms per unit weight. One gram of strontium-90 (Sr^{90}), which has a half-life of about 28 years, has an activity of 147 curies. A radioisotope with a shorter half-life and/or a lesser atomic weight would have an even greater specific activity. It is important to note that the radioactivity per gram is large and that the amount of radioisotope necessary to be of concern as a potential health hazard is extremely minute, usually too small to be determined by gravimetric methods. It can only be measured by special instruments. The total amount of Sr^{90} that has fallen onto the continental United States has been less than 1.5 lbs., i.e., one gram per 5000 square miles, rendering on the average 30 millicuries per square mile. Strontium-90 from this 1.5-lb. source can be traced to milk, wheat, plant, and bone samples.

As to other characteristics of radioactivity, reference is made to readily available textbooks in this field. Depending upon the type of cell absorbing the radiation, the character of the danger varies. As to somatic cells the effect naturally is limited to the irradiated individual, whereas genetic effects may be passed on to the progeny. In general, the more complex the organism, the more vulnerable it is. The lethal dose, 50% at 30 days (LD_{50}), is about 400 roentgens for man but is two or three times greater for fish.

Opinions vary as to the hazards of radioactive fallout. Evidently all ionizing radiations are damaging but at a varying degree, depending on dosage. Some repair of damage caused by ionizing radiations may, furthermore, take place. Thus if the radiation dose does not result in observable changes, a hazard may nevertheless exist, as subsequent generations may show molecular disturbances including genetical aberrations. The concept of a threshold level of radiation consequently implies that changes within certain ranges are limited in scope and any ensuing damage is of a magnitude that can be tolerated. This reasoning is more readily accepted for effects upon the somatic, rather than on the reproductive tissue. When radiation is administered over unequal periods of time the effect is less for the lower dose at a longer exposure. Some repair of a damage, once incurred, evidently does take place, but in a recent experiment by Russell and Russell (1958) with mice, ". . . low dose rates of radiation turned out to be only one-fourth as effective in producing mutations as the same dose given at high dose rates." (Joint Committee on Atomic Energy, 1959).

II. Recent Changes in Oceanic Radioactivity

Most food commodities have shown an increased total radioactivity when compared with conditions prior to 1945. Primary plant products exhibit marked increases above "natural" figures, as the plant ever is the prime recipient of fallout either directly landing on plants or indirectly entering their tissues in the primary production. Animal products may become contaminated basically in two ways, directly or indirectly. Directly this happens through drinking water, inhalation, or when originating from aquatic organisms via gills and integuments. Indirectly it takes place through consuming contaminated food, unless the animal has a selective mechanism whereby one or another radionuclide is selectively screened and does not enter into the metabolic pathways or is absorbed as particle. The situation may conversely be aggravated by radionuclides being selectively received and thereby the risk prevails that they become accumulated in the living organism if not rejected at a similar rate. This selective screening is obviously only relative and rarely absolute.

Pertinent to this analysis is the fact that several food commodities exhibiting no measurable radioactivity prior to 1945 have gradually increased their radiation by 1957 to the values shown in the accompanying tabulation (Lang and Wallace, 1959).

Commodity	No. analyzed samples prior to 1945 with no measurable radiation	No. of samples in 1957	Radiation in 1957 (d./m./g.)[a]
Fish	25	26	0.32
Shellfish	15	32	0.36
Dairy products	26	46	0.55
Tea (whole leaves)	36	88	31.40

[a] Disintegrations per minute per gram.

Several reviews and critical analyses have been published on the likely effect of an increased radioactivity on world fisheries (Revelle *et al.*, 1956; Finn, 1957; Anonymous, 1958; Kreps, 1959). This seems justified since the seas are the recipients of the major portion of the direct fallout due to the fact that they cover an area twice that of the land area. In addition the run-off from the continents carries additional loads to the seas.

III. Uptake and Accumulation by Marine Organisms

Most of the increased radioactivity in commodities is due to fallout from nuclear devices and disposal of atomic wastes. Numerous studies have shown that various aquatic organisms are capable of taking up radionuclides but unfortunately also accumulate considerable quantities of certain such nuclides. Considerable work has been done on the uptake of organisms in White Oak Lake and Columbia River near Hanford, Washington. Foster and Davis (1956) found that the minnow (*Richardsonius balteatus*) could accumulate P^{32} 150,000 times that of the surrounding water, while in the gaddis fly larvae, *Hydropsyche cockerelli*, the concentration factor could be as high as 350,000. They also found that the gross radioactivity of plankton (mainly diatoms) was about 2000 times that of the surrounding water. Krumholz and Foster (1957) estimated the concentration factors for various organisms and radionuclides. These are given in Table I. The high values for P^{32} are partly due to the fact that the phosphate concentration is abnormally low (about 0.03 ppm) in the Columbia River water. These results point to an obvious complication introduced by the effect of the concentration of each element in the sea water, relative to that of the organisms. This has been underlined by Odum *et al.* (1958) in their studies on phosphate. When S^{35} was substituted for P^{32} no uptake could be detected. Sulfate in contrast to phosphate is abundant in sea water in terms of the requirements of the organisms, and in algae sulfur is concentrated only ten times as against several hundred for phosphorus.

TABLE I

ESTIMATED CONCENTRATION FACTORS FOR VARIOUS RADIONUCLIDES IN AQUATIC ORGANISMS AS OBSERVED FROM FIELD STUDIES[a]

		Concentration factors (1000 times concentration)			
Radio-nuclide	Site[b]	Phyto-plankton	Filamentous Algae	Insect Larvae	Fish
Na^{24}	I.	0.5	0.5	0.1	0.1
Cu^{64}	I.	2.	0.5	0.5	0.0
Rare earths	I.	1.	0.5	0.2	0.10
Fe^{59}	I.	200	100	100	10
P^{32}	I.	200	100	100	100
P^{32}	II.	150	850	100	30–70
Sr^{90}-Y^{90}	II.	75	500	100	20–30

[a] Source: Krumholz and Foster (1957).

[b] I.—Columbia River; II.—White Oak Lake.

During the summer some radiophosphorus is taken up by organisms in the waters of the Canadian Ottawa River in which limited discharge of fission products takes place. By the autumn this acquired radioactivity disappears owing to the lowered metabolism of the organisms and the short half-life of radiophosphorus. Traces of Sr^{90} have occasionally been found in the bones, but none in the flesh (Ophel, 1960).

The uptake is most likely to be a normal feature for aquatic organisms and as far as is known is not influenced by radioactivity. Therefore it is noteworthy that long before any fallout, the enrichment factors shown in the accompanying tabulation were reported for marine animals on the basis of wet weights compared to sea water (Noddack and Noddack, 1939).

Element	Enrichment factor	Element	Enrichment factor
Zn	3250	Cd	450
Ag	2000	As	330
Ge	760	Sn	270
Mo	600	Sb	30

Black and Mitchell (1952) found the following concentration effects for marine algae: Mo, 2–15; Sr, 8–90; and Zn, 400–1400. In both field and laboratory observations it was found that zinc and cobalt are taken up rapidly and in high concentrations by plankton (Chipman, 1959).

Goldberg (1957) and Chipman *et al.* (1958) demonstrated that some marine organisms such as mollusks concentrate metabolic ions at levels many times higher than those found in surrounding waters.

TABLE II
APPROXIMATE CONCENTRATION FACTORS IN MARINE ORGANISMS[a]

		Invertebrates		Vertebrates	
Element	Phytoplankton	Soft tissue	Skeleton	Soft tissue	Skeleton
Na	1	0.5	0	0.07	1
Cs	1	10	—	10	—
P	10,000	10,000	10,000	40,000	2,000,000
Sr	20	10	1,000	1	200
Zn	100	5,000	1,000	1,000	30,000

[a] Krumholz and Foster (1957).

The elements which enter biological systems most freely—for example, phosphate, strontium, and zinc—generally show high accumulation factors, presumably in excess of 10,000. The highest values are in phytoplankton, constituting the first stage in the food chain, but this is not invariably so. The magnitude of the enrichment may be greatly influenced by the concentration of salts in the water. Factors of 1000-3000 were reported for phytoplankton by Setter and Golden (1956) in U.S. and Ruf and Müller (1960) in West Germany. A factor of 73 was established for the Boden See (Fast, 1961).

Most of these organisms occur in the food links of aquatic animals. Consequently, it is this ability to concentrate specific ions and thus also the corresponding radionuclides that causes concern, plus the fact that lower animals can usually survive dosages that may be lethal for man. Many findings also point to the alternative possibility that besides accumulation due to normal physiological activities in plants and animals, there may take place an uptake governed chiefly by physical factors, such as pH, ion exchange, concentration differentials, etc. This has been shown largely to determine zinc uptake by *Ulva lactuca* (Gutknecht, 1961). It should be pointed out that aquatic organisms are difficult to study as to the channels of the food chain. Most of them are capable of absorbing nutrients and particularly mineral ions directly from the water via the skin and other integuments. In other words, diet is not the sole source of many compounds. In fish the gills constitute another obvious port of entry. For instance, studies have shown that non-feeding *Tilapia* fish took up no less than 60% of the absorbed Ca^{45} directly from the water, meaning that in effect they would not need a dietary source of this element. This makes aquatic media particularly hazardous as to the ingestion of radionuclides. To what degree this happens with algae is not sufficiently known. As a whole this entire field is in need of extensive investigation. Earlier theories, such as that of Pütter, may need increased attention.

Gileva (1960) established that three fresh water algae—*Scenedesmus, Cladophora,* and *Spirogyra*—showed strong affinity for Fe^{59}, Zn^{65}, and Zr^{95}; lesser affinity for RB^{86} and Ca^{45}; and weak affinity for S^{35} and Co^{60}. Rice (1956) studied twelve marine planktonic algae and found a very strong affinity for Y^{90} but less so for Sr^{90}, although this latter showed a high degree of accumulation in most species.

A study of the uptake by clams of three neutron-induced radionuclides (Zn^{65}, Fe^{59}, and Co^{60}) and a 2-month-old mixture of fission products demonstrated the ability of this marine animal to rapidly concentrate significant quantities of these radionuclides in both the shell and soft tissue (Gong *et al.*, 1957). The uptake of radioactive material in the soft tissue is a metabolic incorporation, while the higher uptake by the shell appears to be a surface adsorption phenomenon. Rate of incorporation by the soft tissues was constant and was highest for the rare earth group of fission products. Uptake of Co^{60}, Zn^{65}, and Fe^{59} was also constant but occurred at a much lower rate. Sr^{89} and $Ru^{103\text{-}106}$ were taken up only in equilibrium with the radioactive medium in the experimental interval studies (Gong *et al.*, 1957). The ability of the clam to concentrate radioelements to a high degree makes it valuable as a biological indicator of radioactivity. It may be particularly useful in assessing contamination of marine areas with low levels of radioactivity. Also essential to an appraisal of the risks involved in contamination of radionuclides is desorption, namely the rate in which absorbed or incorporated radioactive elements are discharged from the body and whether any selectivity pertains to this process, resulting in certain nuclides being retained longer than others. Appreciable differences in this respect both with regard to rate of desorption in different species and with individual radionuclides were observed by Soviet scientists. The amount finally retained after lengthy periods in clean water differs depending on element and organism (Getsova, 1960).

Great importance must be attached to the role of living organisms in the general problem of the spreading of fission products in ocean waters. This ability of different marine animals and plant life to accumulate important radioactive substances (Spooner, 1949; Boroughs *et al.*, 1957; Polikarpov, 1961) is evidently instrumental to a concentration of such radionuclides. As to active transportation, see Section IV, below.

Both field observations (Lowman *et al.*, 1957; Schaefer, 1958) and laboratory experiments (Chipman, 1959) show that zooplankton rapidly accumulates radioactive particles. Chipman states that when such particles are no longer available, the zooplankton soon loses its radioactivity. Oysters, clams, and scallops, like zooplankton, readily accumulate radionuclides, but many of those that reach the digestive tract are never absorbed by the organism.

The highest concentration of radioactivity in Pacific Ocean fish from 1954 was, as indicated below (Section V), found in viscera, with less in bone, skin, and muscle (Saiki *et al.*, 1955). An essential factor in fish is the difference in the rate of uptake directly from water via the gills and the skin and the uptake indirectly via the intake of food. Tomiyama *et al.* (1956) reported that fish took most of its calcium directly from the surrounding water. Goldfish took 50 times more calcium in this way than via a worm diet. Strontium is absorbed 10 times faster from water than from food (Schiffman, 1959).

The coefficients of accumulation of Sr^{90}, Cs^{137}, and Ce^{144} in seaweeds, eelgrass, actinia, mollusks, and crustaceans have been established (Polikarpov, 1961). A certain discharge of Sr^{90} into sea water from decomposing seaweed and the retention and additional absorption of Cs^{137} and Ce^{144} onto organic debris takes place. The ability of these elements to diffuse into sea water is also a decisive factor when appraising the hazard to man from Sr^{90} and Ce^{144} in marine life. Despite the proportionately low coefficients of accumulation of Sr^{90} in marine organisms which are used as food, this radionuclide is nevertheless more dangerous to man (about 100 to 1000 times) than Ce^{144}, which has high coefficients of accumulation, when both are present in the same concentration in sea water. The same is apparently true for all other mammals which feed on sea organisms (Polikarpov, 1961). A very comprehensive study resulting in the establishment of enrichment factors for a great number of fish, invertebrates, and seaweeds used as food in Japan was published by Ichikawa, in 1961. Cesium-137 occupies, as to risks for humans, an intermediate position. There is nevertheless the possibility of Ce^{144} being retained in the upper layers of the ocean by plankton (Harley, 1956). Strontium-90 is a constant source of Y^{90}, which has high coefficients of accumulation in marine organisms (Polikarpov, 1960). Iron-55 (Fe^{55}) and Fe^{59} are produced by neutron irradiation of the corrosion products in reactor coastal systems. Almost every marine animal and plant of economic importance considerably concentrates ions from surrounding water (Ichikawa, 1961). Radioactive ions in nuclear wastes poured into coastal waters would therefore be cause for the organisms living there to accumulate these radionuclides 1000-10,000 times.

Manganese-54 (Mn^{54}) is another radioactive corrosion product found in coastal water and in concentrations as high as 100–10,000 in almost every marine organism. The cephalopods have the highest concentration factor and fishes the lowest (Ichikawa, 1961).

Cobalt-60 (Co^{60}) shows the lowest rate of enrichment among radioactive corrosion products (Ichikawa, 1961). Invertebrates concentrate cobalt more effectively than fishes. Cephalopods have lower values than mussels (Ichikawa, 1961).

The final pattern of accumulation is dependent on a great number of other factors, such as currents, temperatures, the composition of flora and fauna, space distribution, and ecological relationships. All these variables must be taken into consideration when disposing of highly radioactive wastes of the nuclear industry into the depths of the sea. According to the latest data (Vodjanitzhij, 1958; Skopintsev, 1959), the time interval for the rise of bottom waters to the surface in the Black Sea is from 60 to 130 years. In the course of this period Sr^{90} radioactivity would diminish 5 to 30 times.

The half-life of radioisotopes must, however, also be taken into account. Some products may be dangerous to use if eaten fresh but be perfectly harmless after storage, either canned or frozen. Phosphorus-32 for example, has a radiological half-life of 14.3 days. Strontium-90 on the other hand has a half-life of 28 years. Cesium-137, with 27 years half-life, is one of the most dangerous fission elements encountered in fallout and nuclear.

In summary it could be stated that fish and shellfish may be affected by radioactive waste in their environment through (1) direct radiation from the disposed radioactive material, (2) ingestion of food organisms containing concentrated radioisotopes, (3) irradiation by water containing radioactive ions and particles; and (4) contamination by bottom materials rich in precipitated radioisotopes.

IV. Distribution and Movement of Radionuclides

In any analysis of the movements of radioactive fallout material it is necessary to consider not only the fission products as such but also the nuclides which might be created through induced activity or cleavage. Whatever the origin, such radionuclides may naturally (1) remain in solution, (2) be absorbed on the external surface of living organisms or non-living matter, or (3) be accumulated inside various living organisms.

In an extensive study of the distribution of radioisotopes among marine organisms in the western Central Pacific region it was found that specific isotopes are associated with particular organisms and tissues. Of the long-lived fission products Sr^{90}, Cs^{137}, and Ce^{144}, the latter was present in marine organisms in significant amounts; of the induced radioisotopes, $Fe^{55,59}$, Zn^{65}, $Co^{57,58,60}$, and Mn^{54} contribute up to 100% of the radioactivity in marine animals but practically nothing to marine algae. Oceanic fish differ from reef fish in that Zn^{65} ranks first in the ocean fish and Fe^{55} in the reef fish. In comparison, plankton organisms have greater amounts of Co^{60} and lesser of Fe^{55}. The distribution of radioisotopes in terrestrial plants and animals from the same geographical area is greatly different from that of the marine organisms (Seymour, 1959).

The amount and distribution of radioisotopes in the North Pacific a year and one half after the last test series at Bikini-Eniwetok were determined on the basis of analyses of seawater and plankton in samples collected by Operation Troll. These analyses clearly show that the radioactivity in the water from other than naturally occurring radioisotopes ranged from 0 to 570 d./m./l., and in plankton from 3 to 140 d./m./l. per gram of wet sample. At the station with the highest value, 12 samples were taken between the surface and a depth of 653 meters, and the average of the samples was 190 d./m./l. By comparison, the radioactivity in sea water from naturally occurring K^{40} is 736 d./m./l.*

As to the spreading, it has been estimated that in 24 to 48 hrs. the largest fraction of the fallout materials moved through the stirred or mixed water layer, the water above the thermocline, at a rate of about 8 ft. per hr. (Lowman, 1960). In three other surveys during 1956 and 1958, in which samples were collected up to 6 weeks after detonation, the radioactivity turned out not to be homogeneously distributed in the mixed top layer. Nevertheless, one year after the 1954 test series, the radioactivity in the water above the thermocline was well mixed, from which it is concluded that the time required for fallout material in the surface waters of the ocean to blend thoroughly is greater than 6 weeks and less than a year. Some doubt, however, may be expressed as to whether all oceanic waters above the thermoclines really mix thoroughly within a year particularly in areas where no persistent currents prevail.

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* In this chapter the following abbreviations for units of radioactivity are used: d./m./l., disintegrations per minute per liter; d./m./g., disintegrations per minute per gram; c./m./l., counts per minute per liter.

The deep-sea trenches of the world's oceans have been considered as safe "dumps," but evidence is accumulating that they are less reliable (Bogorov and Kreps, 1958). The assumption that they were stagnant regions within the water mass of the oceans is not true. A mixing of such upper and lower waters can take place in less than 5 years. The Soviet Union has investigated 12 of these trenches and contended that they were unsuitable for disposal of radioactive waste. Particularly detailed studies in this respect were made in the Tonga trench, which runs southward 800 miles from the Samoan Islands. This problem was discussed in detail at the second Geneva Conference on Atomic Energy (Anonymous, 1958).

The part played by migrating fishes and other mobile higher organisms capable of accumulating radionuclides still is very obscure. Notwithstanding, if one assumes that fission products from waste effluents or bombs are not evenly distributed but may be concentrated in relatively local areas of the oceans or of bodies of fresh water, a different situation may be created. It is quite conceivable that migratory fishes such as salmon, tuna, and others may accumulate sufficient radioactivity in one area and transport this to another quite some distance away, but in itself devoid of any added radioactivity other than current fallout. Kawabata (1955a, b) made radiological surveys mapping the migration of contaminated fish. In spite of such spreading by living organisms there has developed on the whole a definite depth gradient in radioactivity (Hiyama and Ichikawa, 1957a, b).

There are considerable gaps in present-day knowledge about the spreading of radioactive material in the seas as presented by most researchers in this field. It is now generally recognized that oceans are not typically simple dilution tanks and that free-ranging animal life is quite instrumental in the transporting of radioactive material.

V. Radionuclides in Marine Organisms

A. General Features

The lack of information on the natural frequency of those elements which frequently appear as radioactive in fission products, in a compilation by Vinogradov (1953) of data on the chemical composition of fish, is a good indication that little work up to that point had been done in this respect. Fukai and Meinke (1959), in a more recent publication, have reviewed the literature for data relative to the occurrence of trace elements in sea water and marine organisms, including the soft parts of fishes (see also Chapter 5, by Causeret). The information about trace elements in 10 species of marine zooplankton, based upon spectrographic analyses, has been published by Nicholls *et al.* (1959). *Nitzschia* sp. turned out to be capable of concentrating Zn^{65} to a remarkable degree (Chipman *et al.*, 1958). From these studies it appears that ". . . for any given chemical element there will eventually be found at least one plankton species capable of spectacularly concentrating it" (Nicholls *et al.*, 1959). This is of significance to the consideration of trace elements in fish because many plankton organisms are preyed upon by fishes, and therefore, the fish may have available to them trace elements in a concentrated form.

The number of radionuclides that have been found in fish has been reviewed by Mori and Saiki (1957). Previous workers have found Sr^{89}, Sr^{90}, Y^{90}, Cs^{137}, and Ru^{106} in bones and scales, and Cs^{137}, Ru^{106}, Ce^{144}, Zr^{95}, and Nb^{95} in muscles and viscera. Mori and Saiki also found Zn^{65}, $Cd^{113m,115}$, $Fe^{55,59}$, Mn^{54}, Ba^{140}, and La^{140} in muscle and viscera, between 1954 and 1957. Cd^{113m} was studied by Shirai *et al.* (1957). Further studies indicated that Cd^{113m} and Cd^{115m} were found to be the largest contaminants in bigeyed tuna contaminated in the Bikini tests. Next in importance were Zn^{65}, Sr^{90}, and Y^{90} (Shirai, 1957-1958). Cadmium combines in a specific way with the protein of the blood (Shirai and Mori, 1959).

A good discussion of the radioactivity in marine organisms is to be found in Aten's paper (1958) at the second Geneva Conference. The urgent need for further research in this field was stressed by Revelle and Schaefer (1958) on this occasion.

In general, liver, kidney, gall bladder, and heart were found as the most contaminated parts in the tissues of the animal. Pyloric coeca, stomach, and intestine were weaker in their radioactivity than the above organs; furthermore, the least activity was observed for skin, bone, and muscle. The order of intensity in radioactive radiation in these tissues is not always the same. Different kinds of fish may show different reactions in this respect, e.g., the most radioactive parts detected in dolphin were the liver, gall bladder, and heart, while in the albacore the heart showed no higher radioactivity than other organs (Amano *et al.*, 1955). Dark muscle always held much higher radioactivity than white muscle of the same fish, sometimes in excess of 10 times (Amano *et al.*, 1955).

Fixed in the osseous tissues of fish are Ca^{45}, C^{14}, and Sr^{90}; they remain there a long time (Rosenthal, 1956).

One of two groups of goldfish, *Carassius auratus*, each measuring 2 cm. in length, was reared for periods from 1 to 264 hr. in water containing one of the following isotopes at various concentrations: P^{32}, S^{35}, Ca^{45}, or Sr^{89}. The other group of fish, left without food for 10 days, was reared for the same length of time in the presence of algae of the genus *Spirogyra*, contaminated with the above-listed isotopes (Yoshii *et al.*, 1956-1957). In the first group the intake of Ca^{45} and Sr^{89} was stronger than that of P^{32} and S^{35}, showing the highest counts. In the group feeding on radioactive algae, the results were the reverse. This might be explained by the fact that P^{32} and S^{35} were built into larger organic molecules in the algae while the two others chiefly appeared in an ionic form (Yoshii *et al.*, 1956-1957).

B. CALCIUM-45

Calcium has a varied mobility in goldfish (Dumeste *et al.*, 1960). Insoluble Ca^{45} concentrates in the viscera and to a lesser degree in the scales, fins, and gills. Upon transferral to water that did not contain Ca^{45}, the radioisotope disappeared in a few hours from the scales, fins, and gills, but was still present in the viscera after 15 days in noncontaminated water. When soluble Ca^{45} was used, no radionuclides were, however, found in muscle after 48 hours in water. The muscle concentration rose from 4 to 18 days, and when the fish were transferred to fresh water this higher concentration persisted during 2 to 3 additional days and was still apparent after 7 days. The level in the viscera decreased rapidly for 2 days after the fish was put in fresh water, but was still discernible after 7 days. The rate of absorption of radiocalcium also is intimately related to the swimming activities of the particular fish (Tomiyama *et al.*, 1956b).

In laboratory experiments with guppies it was established by Rosenthal (1956) that the natural decay of Ca^{45} removes 75% of the radioactivity in a year.

C. ZINC-65

Japanese workers have made numerous observations of the Zn^{65} level in marine organisms (Yamada, 1954).

Radioactive zinc present in the surrounding water is rapidly taken up in great amounts by molluscan shellfish, probably due to the great difference between the zinc content of the water and that in the tissues (see further the section on zinc in Chapter 5). Much of the zinc in the mollusks is exchangeable with that of the water. The greatest accumulation is performed by oysters, less by hard-shell clams, and least by bay scallops (Chipman *et al.*, 1958). Several values for the degree of accumulation of this radionuclide in several marine organisms utilized as food have been reported by Ichikawa (1961).

The marine diatom *Nitzchia closterium* takes up large amounts of Zn^{65} when it is present in the sea water. Although the greater part of the zinc of the cells is exchangeable with that of the water, very little accumulated Zn^{65} leaves the cell when the organism is resuspended in nonradioactive sea water (Chipman *et al.*, 1958). This species of marine phytoplankton appears to accumulate considerable amounts of zinc. When it is used as forage by fish, either directly or indirectly, the zinc might inadvertently accumulate in certain fishes. This underlines the importance of extensive studies of major foods—plankton, invertebrates, or fishes—on which food fish depend for their development.

In samples from the western Pacific Ocean and from the United States, Zn^{65} was identified in tuna muscle (Yamada *et al.*, 1955b; Kawabata, 1956; Hiyama, 1957; Saiki *et al.*, 1957) and was found in trace quantities in foods analyzed by Murthy *et al.* (1959). The values reported by Murthy *et al.* were higher for oysters and clams than for land crops, and in terms of micromicrocuries per kilogram were as follows: Chesapeake Bay oysters in Jan., 1959: 178, and in March, 1958: 124; East Coast hard-shelled clams in May, 1958: 50. These high values are readily explained by the finding that oysters, clams, and scallops concentrate large amounts of zinc, frequently thousands of times above its level in sea water (Chipman, 1959). Coefficients of accumulation—i.e., ratio of radioisotope concentration in the organisms to that in water 16–32 days after the beginning of the experiments—of Sr^{90}, Ru^{106}, Cs^{137}, and Ce^{144} from water solutions with low concentrations of these isotopes (of the order of 10^6 to 10^5 curies/l.) were determined in laboratory experiments for 30 species of fresh-water plants and for 18 species of fresh-water animals. On the average, plants showed higher coefficients of accumulation than animals; different species have very different coefficients of accumulation of different elements. For strontium and cesium coefficients of accumulation are lower on the average than for ruthenium, and especially cerium. Coefficients of accumulation of different elements by different species may widely differ (from about 10 to more than 50,000).

When the common carp was cultivated in water containing Zn^{65} at 45,000 c./m./l., this isotope was deposited chiefly in the gills and kidney. Most other tissues contained minor amounts. When injected, it accumulated chiefly in the kidney, followed by the hepato-pancreas, heart, intestines, gill, scale, caudal fin, gall bladder, skin, vertebrae, and muscle in the mentioned order (Saiki *et al.*, 1955). In goldfish experiments it was established that Zn^{65} enters the fish body through metabolic pathways. It is not directly absorbed from the water (Minura and Tsunashima, 1956).

Marine fish quickly take zinc into the body from the digestive tract. Much of it is excreted rather promptly. High blood concentrations of Zn^{65} from feeding of the nuclide to fish were quickly followed by rapid uptake by the kidney, liver, and other internal organs. The Zn^{65} concentrations of these and the blood very quickly declined after reaching this early peak. The liver had the greatest accumulation. A slow and long-continued accumulation took place in bone, integument, and muscle tissues (Chipman *et al.*, 1958).

Although there was an immediate loss of accumulated Zn^{65} when marine fish, having been exposed to the zinc-nuclide in sea water, were returned to flowing nonradioactive water, a small percentage remains, with only very slight loss, over periods of many days.

When the clam *Meretrix meretrix luzoria* was immersed in the sea water containing Zn^{65}, this element accumulated chiefly in the gills, mantle, viscera, and other soft tissues. Only little radioactivity was found in the hard tissue (shell), and about 40% of it was lost in 2 days after returning the clams to normal sea water (Saiki *et al.*, 1955).

West Coast oysters contain many times higher quantities of Zn^{65} (Perkins *et al.*, 1960) than those of the Chesapeake Bay. This is presently explained by the greater fallout in the former area, chiefly due to the Bikini tests.

D. STRONTIUM-90

Gobioid fishes were reared in sea water to which had been added various amounts of Sr^{90} and calcium. The higher the concentration of strontium in the environmental water, the greater the uptake by fish tissues—in contrast to calcium, which was not taken up in large quantities as the concentration rose (Ichikawa and Hiyama, 1957). This is an important finding. If applicable to all fishes, it would mean that calcium is not able to block the free flow of any amount of Sr^{90} into the fish body and the bone tissues. (In contrast, the cow is able to screen strontium when sufficient calcium is present.) This was confirmed by Rosenthal (1957, 1960), at any rate to the degree that in several fresh water fishes he found the Sr/Ca ratio to be almost one. Contrary to this, Boroughs *et al.* (1957) found that marine *Tilapia* discriminate against strontium relative to calcium. This basic difference between fresh water and marine fishes had recently been substantiated by Ichikawa and Oguri (1961), comparing eels from fresh water with those from marine sources.

The discrimination against strontium was greater in marine eels. These authors relate this difference to the higher concentration of both calcium and strontium in sea water. Soviet studies (Kirpicnikov *et al.*, 1956) also confirm that marine fish discriminate against strontium in favor of calcium either by excreting it faster or by absorbing less.

An important observation made by Tomiyama *et al.* (1956b) was that there exists a remarkable difference between fresh-water and salt-water fish as to the radioactivity encountered in the gastrointestinal tract after exposure to such compounds; very high values were found in the intestines of marine fish and very low values in fresh-water fish. This is not yet explained.

Nonetheless, Japanese findings report that the Sr/Ca ratio in marine fish and shellfish was the same as in the surrounding sea water (Hiyama and Ichikawa, 1957a). Sr^{90} first replaces the strontium in the muscles and only gradually moves into the bones. When gobioid fishes were reared in Sr^{90} concentrations ten times higher than a control series the accumulation increased in the same ratio (Hiyama and Ichikawa, 1957b).

Tuna fish caught after hydrogen bomb tests showed 0.2% Sr^{90} in the muscle (Nagasawa *et al.*, 1956). This was not the case when 87 tuna and swordfish livers were examined subsequently (Nagasawa *et al.*, 1957).

In laboratory experiments, strontium radioisotopes are taken up and deposited in the shells of oysters, clams, and scallops but not in the soft tissues (Chipman, 1959).

In both field and laboratory tests (Chipman *et al.*, 1958) it was found that marine fish absorb few of the fission products from the digestive tract and do not concentrate strontium radioisotopes in muscle, but do absorb Zn^{65} very rapidly (see p. 622). As a whole the enrichment factor of strontium is very small, with the exception of that for brown algae, which is 8-40. This group of algae accumulate strontium more than red algae (Ichikawa, 1961), which follow the general pattern for other marine organisms.

E. CESIUM-137

Although little Cs^{137} has been found in the marine organisms from the Bikini-Eniwetok area, this radionuclide has been taken up and concentrated in the muscle of fish and shellfish in laboratory experiments, and, therefore, is regarded as the fission product with the greatest potential hazard. The conditions that make for a higher concentration of Cs^{137} in the laboratory than in the field are not known. Analysis of coconut crab (*Birgus latro*) muscle collected at Rongelap Atoll at three different dates in 1958 and 1959 showed no correlation between K and

Cs^{137} and no difference in the time of collection. The dry weight Cs^{137} readings varied from 173 d./m./g. to 28 d./m./g. (Chakravarti and Held, 1960). In the field, the concentration of cesium in four types of plankton was less than in sea water, as determined by Ketchum and Bowen (1958), which indicates that there is not a great demand for cesium, at least by some types of plankton.

Pendleton and Hanson (1958) report that carp may concentrate Cs^{137} by a factor of no less than 3000. Twenty grams of this flesh contains the maximum dose considered permissible for man.

When Sr^{90} and Cs^{137} were injected directly into the carp muscle, they accumulated chiefly in the skeleton, whereas Cs^{137} was largely retained in the heart and kidney but was found in both soft and hard tissues.

The extensive accumulation studies by Ichikawa (1961) established that the concentration factor for Cs^{137} is around 10 in fishes and about 1 in seaweeds.

F. CERIUM-144

The predominant fission product contributing to total radioactivity 0.85 to 3 years after detonation is Ce^{144}. Because Ce^{144} is so abundant in fallout, it is reasonable to expect that food will be contaminated by this radionuclide.

A high level of radioactivity was detected in clams of the *Corbicura* sp. at Ibaraki in Japan (see Table III). This was due to small amounts of Ce^{144}. The concentration of this radionuclide in the sediment of the set was 1 mμc./g. of dried sample (Nezu *et al.*, 1961). This amount corresponded to that found in 5 liters of surrounding sea water. The concentration of Ce^{144} in sediment was about 100 times higher than that of Sr^{90}. As this clam lives in brackish waters, it is encountered in marsh sediments. The radioactive contamination of such marsh beds has its origin in fallout (Nezu *et al.*, 1961). It may therefore be safely

TABLE III

Ce^{144} AND Sr^{90} IN SAMPLES FROM THE IBARAKI REGION, JAPAN[a]

Sample	Date of sample	mμc./kg. (wet weight)		mμc./g. of ash	
		Ce^{144}	Sr^{90}	Ce^{144}	Sr^{90}
Clams, muscle	June 1960	68.0–3.6	2.8–0.8	15.4–0.8	0.65–0.19
Cuttlefish (total)	Feb. 1960	77–9.0	1.6–0.6	4.67–0.56	0.10–0.038
Crucian carp bone	Apr. 1960	31–10	705.8–8.1	0.30–0.10	6.94–0.081
Mixed cattle bones (cattle and horse)	Jan. 1960	932–24	9293–60	3.10–0.80	30.98–0.20

[a] Source: Nezu *et al.* (1961).

assumed that Ce^{144} was deposited in the marsh bed by fallout and then absorbed by the clams.

The higher levels of Ce^{144} in clams, as compared with levels in the other biological samples, are consequently not unexpected. Clam flesh, on a dry matter basis, is an even more potent source than bones of carp and terrestrial animals. The concentration of Ce^{144} in clams in April, 1959, was about 700 μμc./kg. of clam muscle wet weight, and decreased to 70 μμc. by July of the same year.

G. Lead-210

The distribution of Pb^{210}, which enters the oceans subsequent to its production in the atmosphere by radon-222 decay, shows an increase with depth in sea water. It is suggested that the marine biosphere is responsible for the conveyance of lead from surface to deeper waters (Rama *et al.*, 1961).

The residence time of lead in the deep oceans before precipitation to the sediments is of the order of 10,000 years. The markedly shorter residence time in surface waters emphasizes the distinction between the mechanisms of transport of lead from the mixed to the deep waters and from the deep waters to the sea floor.

Observations on the distribution of barium in the oceans have indicated the importance of biological activity in the conveyance of heavy metals from the mixed to deeper waters (Chow and Goldberg, 1958).

H. Miscellaneous Radionuclides

In skipjacks caught after the 1956 tests, several additional radionuclides, besides those mentioned above, were identified by Japanese scientists (Tozawa *et al.*, 1957). The alkali-earth metals were represented by Ba^{140} and La^{140}. Noteworthy was the finding that substantial residual activity could be attributed to Cd^{113} (Amano *et al.*, 1956), but also to Fe^{55} (Saiki *et al.*, 1957). Weak activity was also found as tied to the Sn-fraction. The liver was in all cases a major seat of activity. Several of these radionuclides have not been identified so far. Shirai *et al.* (1957) proved one to be a cadmium nuclide, namely Cd^{113m}. Manganese 54 was found for the first time in 1958 as a radioactive contaminant in the liver of big-eyed tuna (Shirai and Saiki, 1958b). Furthermore, Y^{90} and Sr^{90} were confirmed (Shirai and Saiki, 1958b, c). In a study of skipjack from the Bikini area, soon after the explosion, two iron nuclides, Fe^{55} and Fe^{59} (Amano *et al.*, 1956), were confronted beside Zn^{65}. This was confirmed by Shirai and Saiki (1958a, b, c), and in addition Cd^{115m} was identified.

VI. Carbon-14

In the testing of nuclear weapons to date, large amounts of radiocarbon have been synthesized and injected into the earth's carbon cycle, specifically into the atmosphere. From this reservoir, such radiocarbon makes its way into other carbon reservoirs through numerous mixing processes, with the result that its concentration at various places in the carbon cycle is rising, and consequently also in the oceans. The amount of bomb-produced C^{14} stored in living organic materials was in 1960 calculated to be 0.3×10^{27} atoms (Broecker and Olson, 1960). This in effect is a minor part of the total inventory. That amount of bomb-produced C^{14} which has entered was also computed by these research workers. If all of this oceanic C^{14} had remained in the upper 100 meters of water, the C^{14}/C^{12} ratio of the surface layer should have risen 30 per mill between March 1, 1955 and July 1, 1959. Ocean-water measurements available to date showed an increase of this order. The C^{14} load of the atmosphere is expected to reach its peak C^{14}/C^{12} level before 1963, and the surface of the ocean will reach its top value between 1970 and 1975. The ratio for the atmosphere will have dropped to one-half the peak value between 1975 and 1980, and the ratio for the surface ocean will have dropped proportionately by 1990. In about 50 years the C^{14}/C^{12} level in the atmosphere will have returned to the pre-bomb level. This means that this factor has to be recognized as an interfering agent in ocean life for quite some time. To what degree is difficult to establish. The very fast increase in the C^{14} activity in the atmosphere due to atomic bombs was reported in a special study by de Vries (1958).

It should be noted that there is a shortcut for carbon, directly from the surrounding sea water into the basic metabolism of fishes. After 24-, 48-, and 72-hour exposure of fish to a radioactive medium $Na_2C^{14}O_3$ added to the aquarium water, great amounts of labelled carbon were found in blood serum, liver, bones, intestine, brain, scale, eyes, and kidneys, and a lesser amount in the muscles, bile, and erythrocytes of the blood (Sorvachev and Belokorytov 1960). Inorganic carbon while entering the organism takes part in the metabolism, being transformed into organic carbon containing compounds such as glycogen, proteins, fats, and some amino acids of the extractive substances of the liver, muscles, and intestines.

VII. Radioactive Pollution and Hazards

A. General

Surveys made of the Marshall Islands one and two years after their accidental contamination by fallout, presumably from the Bikini tests, revealed the presence of readily detectable radioactivity in clams. The level was significantly higher per unit body weight than in most marine specimens analyzed. The extraordinary ability to concentrate radionuclides dispersed in sea water was evident from the fact that the gamma activity in clams collected off the Eniwetok Proving Ground was about 2000 times greater than that of sea water. The concentrating ability of the clam probably involves filtration of large volumes of water. It is estimated that in one year a 3-in. clam filters about 2.3×10^4 l. of water (Gong *et al.*, 1957).

The occurrence of radioisotopes in aquatic organisms exposed to reactor effluent water was studied by Davis *et al.* (1958) and reported to the second Geneva Conference. A special conference on the disposal of radioactive wastes was held the following year in Monaco. The proceedings are published and contain a great deal of pertinent information on these matters (International Atomic Energy Agency, 1960).

An area where radioactivity is being added continually is in the Pacific Ocean at the mouth of the Columbia River, which receives low-level liquid from the Hanford plutonium production reactors. The total radioactivity entering the ocean at this point everyday is about 1000 curies (U.S. Atomic Energy Commission [AEC], 1960). The fillets of plaice caught in these waters polluted by nuclear wastes have increased their radioactivity only to a minor degree, from 3.6 to 9.0 mμc./g. On the other hand, it has been reported that during the fall of 1957, 2.7 lbs. per week of Columbia River whitefish would attain the maximum permissible dose (Watson and Davis, 1958). The major long-lived radioisotope Zn^{65}, being introduced by effluent water, is encountered in seafood harvested near the mouth of the Columbia River (Murthy *et al.*, 1959). Tsivoglov *et al.* (1958) reported studies on the radium concentrations in algae, bottom animals, and fish, resulting from the discharge of radioactive waste material into different streams from fourteen plants then in operation for the refining of uranium ore. Some concentrations were in excess of permissible minima. The radium content of algae samples taken from the stream below such a plant had 1500 times more radium as compared to samples taken from the stream above the plant. These findings have particular public health significance as this radionuclide has a long half-life.

According to findings about the discharges from the Windscale reactor in Britain the closest watch is required for ruthenium-106 (Ru^{106}). This radionuclide accumulates in the red algae *Porphyra umbilicata*. This actually is consumed as food by the local residents as a chief ingredient in laver bread. Its content of Ru^{106} went up to 181 mμc./g. from 2.2 mμc./g. after wastes from this reactor spread around.

The quantity of low-level wastes dumped to date in the Atlantic and Pacific is infinitesimal, compared to the amount the British are piping into the Irish Sea. The amount of Sr^{90} that can be dumped at each site is according to NAS reports recommended to be restricted to 250 curies annually. The atomic waste entering into shallow waters near Cape Cod consists largely of one of the less dangerous radioactive elements.

In the United Kingdom 1000 curies were originally piped into the Irish Sea each month. As operations expanded this figure rose to 8500 curies—based on the calculation that the consumer of 2-1/2 oz. of laver bread daily should not ingest more than the maximum permissible limit of Ru^{106}. It is anticipated this figure will be reduced when new plants for concentrating wastes comes into operation and alternative waste disposal methods are introduced (New Scientist, 1962).

B. ZINC-65

From March 1961, Zn^{65} counts in Thames River (Connecticut) oysters were as much as 10 times those reported for Chesapeake Bay oysters, but only about 1/40 of the Zn^{65} content of West Coast oysters. The highest levels of radioactivity were in oysters from a bed situated opposite the United States submarine base, in March, 1961 (1637 μμc./kg. of moist tissue). Notwithstanding, none of the samples assayed showed sufficient amounts of radioactivity to represent a health hazard (Fitzgerald *et al.*, 1962).

The data show that in March 1960, there was a peak in the concentration of Zn^{65}, with a marked reduction for April and a continued decline in May. Total zinc did not increase in a corresponding fashion, which points to a rise in available radioactive zinc.

Oysters in the Willappa bay, affected by nuclear pollution from the Hanford reactor, showed a 2×10^5 concentration. All other seafoods were lower in this nuclide, as were samples of canned oysters from Japan (Perkins *et al.*, 1960). Zn^{65} was found in all samples of terrestrial food and feed when Columbia River water, receiving the effluents from this reactor, had been used for irrigation. All humans who had drunk this water also carried this radionuclide, but in all cases in submaximal quantities. It can therefore be concluded that most aquatic organisms also were affected and incorporated Zn^{65} (Perkins and Nielsen, 1957).

Special precautions will in the future be required to dispose of radioactive wastes from nuclear-powered ships (NAS-NRC, 1959).

VIII. The Bikini Tests and the "Dragon" Incident

In order that shipping should not be endangered, a prohibited area of some hundred kilometers in all directions was proclaimed around the Bikini testing place. Thus immediate and acute radiation damages were supposed to be avoided. Nevertheless these tests caused the unfortunate "Dragon" incident, when a Japanese fishing boat was caught in the direct fallout from this explosion and its crew became contaminated. Furthermore, the fallout absorbed by the sea water in the test area was carried by currents to water outside the prohibited area. Due to this, Japanese fishermen who were at considerable distances from the test area had to destroy their catch, as it was found to be contaminated. It was reported that altogether 80,000 tons of landed fish were discarded due to excessive radioactivity. For data on the radioactivity of these tuna catches see Kiba *et al.* (1954). Besides tuna the valuable marlins were also seriously contaminated (Ichikawa and Hiyama, 1957). The Sr^{90} concentration in tuna-like fishes in the south Pacific showed an increasing gradient, counted from the test site (Hiyama and Ichikawa, 1957a, b).

A great number of research reports covering various aspects of this incident have been published by several Japanese research workers and their respective collaborators (see list of references under the following: Kawabata, Nagasawa, Shirai, Tozawa, and Yamada).

Intense studies and monitoring of radioactivity in the Pacific followed. Water which had become radioactive as a result of the Bikini tests was carried in a northwesterly direction. It took a whole year for this water to reach the south coast of Japan. Radioactivity increased in waters covering a large area between Hawaii, the Philippines, and Japan, and reached levels about 10 times as high as in the Atlantic ocean. Exhaustive tests reveal very little decrease in subsequent years.

IX. Sea as against Land

The natural radioactivity of the oceans is much less than that of land. But the major portion of the ocean harvests come from coastal waters, where the runoff from the land area reaches the oceans and radioactive pollutants may add to the local concentration of radionuclides.

Present knowledge about the oceans currents or the mixing rates of the deepest layers of water with the surface does not allow safe predictions as to dilution and spread of such contaminants. It is well established that the oceans, like rivers and lakes, are not a simple dilution tank. This is furthermore complicated by the fact that so many microscopic organisms, plankton and shellfish, concentrate radioactivity by many thousands or even millions of times the level in the surrounding water. Fish range freely between deep ocean and continental shelf. Shrimp, squid, and other organisms help to spread radioactive elements from the depths to the surface.

The true effect of a permanent increase in the radioactivity of the seas cannot yet be anticipated.

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CHAPTER 19

Trends in Utilization of Fish and Shellfish

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I. Introduction

It is becoming increasingly difficult to differentiate major trends in the utilization of fish and shellfish catches. Primarily, this is due to the fact that a substantial portion of the fish catch nowadays is processed more than one way. In other words, there is an appreciable discrepancy between the methods employed for primary utilization and the preservation methods which industry uses for final preparation of the products for market. In the future it would be most desirable if a clear distinction could be made between the handling and preservation of the original catch, and the final processing and marketing of the fish. The utilization pattern would then emerge as quite modified in many countries.

A few examples will clearly illustrate these implications. More and more fresh market fish is not actually the original raw fish as captured but fish which has been frozen and then defrosted and, in many cases, also filleted. Another example: only very small quantities of fish are now preserved directly by smoking. Most of the raw material being used for this purpose consists of either salted or defrosted frozen fish. Furthermore, freezing has moved up as one of the major methods for rapid preservation of vast quantities of raw material and makes a substantial contribution to the canning industry by providing readily available, high-quality raw material. This is largely true in the Soviet Union, and applies to the French sardine industry as well as the salmon and tuna industries of the United States. Many more examples could be mentioned to illustrate this growing gap between the primary utilization and the final pattern, which might be some two or three stages removed from the initial preservation. Very few statistics allow an adequate analysis of this problem. The situation is further complicated by the fact that although most figures refer to primary utilization, some countries submit official figures showing the final use. A few such cases will be anayzed further below. There is no consistent ruling in this respect. In a few cases, the figures reflect both the primary and secondary utilization, that is, the same fish is counted both as frozen and canned or both as salted and smoked, which also contributes to the confusion. This means that often the total amount of fish which, according to the statistics, is being utilized may exceed the total catch, thus implying that the country imports, which may not be true. Recognizing these difficulties, certain general trends can still be envisoned and a few important conclusions drawn as to the present trends in fish and shellfish utilization (see Tables I and II).

II. Fish Catch per Capita

The utilization pattern naturally is largely determined by the size of the catch in relation to the population of each fishing nation. It is one thing to meet the domestic needs of a human population; to what degree profitable and reliable markets are developed in other countries is quite another matter. As one uses the term "subsistence fishing" in relation to the fisherman's own family, one may use this term in relation to a whole country. Most nations are in this sense either self-sustaining with fish, or short of their needs and have to resort to importation to fill the regular needs. The United States is the leading buyer on the

TABLE I
UTILIZATION OF TOTAL FISH CATCH BY AREA (1960)

Area	Total catch (1000 metric tons)	Fresh (%)	Freezing (%)	Curing (%)	Canning (%)	Reduction (%)	Miscellaneous (%)
World	37,700	40.0	9.0	19.0	9.0	20.0	3
Japan	6192.5	22.6	12.8	43.6	6.7	13.9	0.4
Soviet Union	3500	15.5	30.5	30.2	11.8	10.8	0.1
Peru	3501.4	2.3	0.5	0.6	1.9	94.7	—
United States	2796.9	30.0	11.2	1.3	22.8	34.4	0.2
Norway	1598.9	10.8	9.7	26.8	3.0	48.8	0.1
India	1159.9	47.9	—	43.7	—	8.4	—
United Kingdom	1070.6	79.8	11.2	2.6	0.9	3.0	2.4
Canada	915.2	20.6	29.9	30.8	7.2	9.3	2.4
Spain[a]	836.7	65.9	—	18.9	12.4	2.8	—
West Germany	743.0	35.1	5.2	14.8	26.5	18.3	—
Indonesia	753.7	80[b]	—	20[b]	—	—	—
Canada (excluding Newfoundland)	713.2	22.0	22.0	17.3	9.5	25.5	3.7
Denmark	581.2	22.7	12.1	2.6	3.1	50.1	9.4
Iceland	592.8	7.8	42.4	31.1	0.1	18.6	—
France (including Algeria)	521.1	60.2	—	23.7	16.1	—	—
Philippines	475.8	62.1	—	37.9	—	—	—
South Africa[c]	465.8	19.8	6.1	15.5	11.6	46.8	0.2
South Korea	342.5	82.4	0.1	14.0	2.5	—	1.0
Netherlands	314.7	47.5	3.7	29.0	8.5	4.8	5.1
Pakistan	304.5	71.8	0.5	22.6	—	5.1	—
Newfoundland[a]	294.1	2.2	35.1	53.0	0.1	—	9.7

TABLE I (*continued*)

Area	Total catch (1000 metric tons)	Fresh (%)	Freezing (%)	Curing (%)	Canning (%)	Reduction (%)	Miscellaneous (%)
Chile[b]	272.8	24.7	2.8	0.1	9.4	63.0	—
Italy	212.2	86.8	3.4	6.2	3.6	—	—
Portugal	202.8	7.7	—	92.3	—	—	—
Morocco[a]	161.8	7.7	11.1	0.2	18.5	62.4	—
Faeroe Islands	109.4	22.1	4.6	72.9	0.1	0.4	—
Argentina	100.9	51.7	4.8	0.8	37.8	5.0	—
Turkey[a]	96.7	72.7	1.2	24.2	1.8	1.3	0.3
Venezuela[b]	83.3	39.4	—	20.9	39.7	—	—
Greece[b]	82.0	62.8	5.0	13.0	1.2	—	—
Finland	66.0	65.8	15.2	11.5	1.5	6.1	—
Australia	60.7	64.7	20.8	—	13.2	—	1.3
Belgium	52.5	77.1	11.0	6.0	3.0	3.0	—
Ireland	42.8	83.4	2.0	12.6	—	2.3	—
Colombia	29.7	74.1	—	14.1	—	—	11.8

[a] Figures for 1958.
[b] Figures for 1956.
[c] Figures for 1959.

Table II

Utilization of Food Fish by Area (1960)

Area	Catch (1000 metric tons)	Fresh (%)	Freezing (%)	Curing (%)	Canning (%)
World	29,300	51.9	11.7	24.7	11.7
Japan	5309.6	26.4	14.9	50.9	7.8
Soviet Union	3048.5	17.4	34.2	33.9	13.2
Peru	185.6	43.3	9.4	11.3	35.8
United States	1828.9	45.9	17.1	2.0	34.9
Norway	802.3	21.1	19.0	52.4	5.9
India	1062.5	52.3	—	47.7	—
United Kingdom	1012.3	84.3	11.8	2.7	.95
Canada	808.1	23.3	33.9	34.9	8.2
Spain	813.0	67.8	—	19.4	12.8
West Germany	607.0	43.0	6.4	18.1	32.4
Indonesia	753.7	80.0	—	20.0	—
Canada (excluding Newfoundland)	517.7	31.1	31.1	24.4	13.4
Denmark	235.5	56.0	29.9	6.4	7.6
Iceland	482.4	9.6	52.1	38.2	0.12
France (including Algeria)	521.1	60.2	—	23.7	16.1
Philippines	475.8	62.1	—	37.9	—
South Africa	246.9	37.4	11.5	29.2	21.9
South Korea	339.1	83.2	0.10	14.1	2.5
Netherlands	283.4	52.7	4.1	32.2	9.4
Pakistan	289.1	75.6	0.52	23.8	—
Newfoundland	265.6	24.4	38.9	58.7	0.11
Chile	101.0	66.8	7.6	0.27	25.4
Italy	212.2	86.8	3.4	6.2	3.6
Portugal	202.8	7.7	—	92.3	—
Faeroe Islands	109.0	22.2	4.6	73.2	0.10
Venezuela	83.3	39.4	—	20.9	39.7
Argentina	95.9	54.4	5.1	0.84	39.8
Turkey	95.4	73.9	1.2	24.6	1.8
Finland	62.0	70.1	16.2	12.2	1.6
Greece	82.0	62.8	5.0	13.0	1.2
Australia	59.9	65.6	21.1	—	13.4
Belgium	51.0	79.5	11.3	6.2	3.1
Ireland	41.8	85.4	2.0	12.9	—
Colombia	26.2	84.0	—	16.0	—

TABLE III
FISH CATCH PER CAPITA[a]

Area	1959	1960	Area	1959	1960	Area	1959	1960
Iceland	3720.3	3368.2	Soviet Union	13.6	14.2	Ghana	7.3	4.7
Faeroe Islands	2564.7	3366.2	South Korea	16.6	13.7	Cuba	4.3	4.5
Greenland	1153.3	1243.8	Morocco	13.7	13.3	Kenya	3.5	4.3
Norway	452.0	445.7	France	10.8	13.0	Italy	4.4	4.2
Peru	190.0	325.3	World	12.0	12.6	Jamaica	5.0	4.2
Aden	162.6	148.7	Venezuela	12.8	12.6	Tunisia	3.9	4.0
Denmark	148.2	126.9	West Germany	14.5	12.1	Brazil	3.3	3.8
Southwest Africa	—[b]	98.8	Congo (Belgian)	11.1	11.0	Turkey	3.6	3.6
Japan	63.3	66.2	Ecuador	8.6	10.0	Egypt	3.4	3.4
Angola	58.8	54.7	Greece	10.0	9.8	Pakistan	3.3	3.4
Portugal	47.2	52.1	North Korea	—[b]	9.3	India	2.0	2.5
Canada	60.2	51.3	Uganda	8.5	9.2	Algeria	2.0	2.5
Chile	36.5	44.5	Thailand	9.4	8.6	Uruguay	2.6	2.4
South Africa	31.7	36.6	China	7.5	—[b]	Colombia	1.5	2.1
Sweden	33.6	33.9	Belgium	6.3	7.0	Sudan	1.7	1.9
Spain	25.0	31.0	Tanganyika	6.6	6.5	Yugoslavia	1.6	1.7
Cambodia	34.4	30.0	Israel	6.4	6.5	Rhodesia and Nyasaland	1.3	1.6
Netherlands	28.2	27.6	Poland	5.4	6.2	Hungary	1.3	1.5
Taiwan	24.1	24.4	East Germany	5.9	6.1	Iraq	1.3	—[b]
Malaya	21.8	24.2	Australia	5.6	6.0	Puerto Rico	1.2	1.3
United Kingdom	20.8	17.5	Mexico	5.7	5.7	Bulgaria	0.9	0.9
Philippines	20.9	17.4	Ceylon	4.8	5.3			
New Zealand	17.8	17.2	Burma	5.0	5.0			
Ireland	13.6	15.1	Argentina	4.3	4.8			
Finland	15.3	14.7						

[a] Kilograms per year.
[b] Figures not available.

food fish market, importing in excess of one billion pounds—chiefly shrimp and frozen whitefish fillets (see further section XX, below).

A few countries constitute excess-catch regions and have been converted into large raw material bases for fish, providing several countries in this respect. Such activities have extensive preservation as a prerequisite. One way of gauging the significance of such fish provision to the world market is to measure the total fish catch per capita. In this way one can readily indicate which are the truly leading nations of the world, not in terms of absolute volume, but judged on the basis of total annual catch per capita. Table III gives these figures for a number of countries. The North Atlantic region—Iceland, the Faeroe Islands, and Greenland—takes the lead with no less than 1.2 to 3.7 metric tons per capita—far above any reasonable individual consumption. Relative to active fishermen this figure gets still greater. Salting used to be the chief method for preserving large excess catches. Freezing is gradually taking its place. Several minor regions—some Pacific islands and several African colonies—also show notably high catch figures per capita, as the accompanying tabulation indicates (average, 1958-1959).

Region	Catch per capita (kg/year)
St. Pierre and Miquelon (Gulf of St. Lawrence)	1880.0
U.S. Samoa (South Pacific)	577.3
Spanish Sahara (Tropical Africa)	307.7
Melilla (North Africa)	98.8
Ceuta (North Africa)	82.0

In most of these cases, preserving and trading is limited and most of the catch is eaten locally. Some is possibly wasted by not reaching the consumer prior to detrimental spoilage.

III. Marine and Fresh-Water Characteristics

A. UTILIZATION PATTERN

The utilization patterns for fresh-water and salt-water fish are basically quite different. Fresh-water catches are generally distributed shorter distances and require less intense processing. In most countries most of the fresh-water fish is eaten within a reasonably short distance from the area of capture. There seem to be only two major exceptions to this general rule. One is the mainland of China, where an extensive network of refrigerated warehouses and fish processing plants are being installed around major lakes. The production of these lakes has been increased considerably to serve distant populations with an important protein addition. This is particularly true of the large salt-water lake of the interior highland, Koko-nor (see further Chapter 7).

The second exception is offered by the postwar development in continental Europe, Canada, and the United States of combining fish cultivation with freezing or canning plants. Japan has recently introduced canned rainbow trout on the United States market. Frozen rainbow trout from cultivated sources in Denmark and Japan is being marketed in the United States in competition with similar trout from domestic establishments. In Denmark cultivated trout from 425 ponds constitute 90% of all fresh-water fish. Their annual production of such trout now exceeds 6000 metric tons (1960). The annual feed consumption of these trout ponds amounts to 45,000 tons, mostly fish and fish offal (Nørgaard, 1961).

Present development plans in the Soviet Union have been based on fish cultivation organized on a regional basis to provide the local population. Not only are major areas provided with fish-raising ponds, but most major cities are establishing sizeable fish-producing centers in their vicinity. This fish will probably reach the local market without any preserving operation other than simple icing, combined with a rapid delivery.

Inland fisheries seem amenable to considerable development not only by a better management of the wild stocks in lakes and rivers, but also by applying improved methods of fish culture in enclosed bodies of water, such as ponds, reservoirs, and irrigation systems. In 1960 slightly over 4 million tons of fish came from the inland waters, and half of that originated in Asia, the center since ancient days for artificial fish raising. The true quantity, however, exceeded this figure, as fishing in local waters constitutes a major basis for subsistence for the population throughout Southeast Asia and China. Fish culture is most essential in areas with limited transportation and restricted storage facilities. In some cases it even turns out to be more economical than investment in those two areas of distribution. It should therefore be noted that any expansion of fish cultivation will have its immediate effect on the utilization pattern in general for each individual country. The cultivation of fish in brackish and salt-water is important in many countries, such as Indonesia, the Philippines, and China. No less than 441,720 tons of cultivated aquatic products—emerged from marine sources in China (Saburenkov, 1961).

B. Comparisons between Relative and Absolute Quantities

Table IV shows on one hand, those countries which entirely or to an overwhelming degree depend on fresh-water fish and, on the other

TABLE IV
FRESH WATER FISH COMPARED TO TOTAL CATCH

Area	1958			1959			1960			% of World fresh water catch 1959–1960
	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	
World	32,100.1	3810.0	11.9	35,330.0	4300.0	12.2	37,730.0	4370.0	11.6	100
China	4060.0	1560.0	38.4	5020.0	2274.0	45.3	5800	2600	45	56.2
Soviet Union	2620.0	460.2	17.6	2760.0	465.4	16.9	3051.0	431.6	14.2	10.3
Indonesia	685.0	264.0	38.5	700.0	300.0	42.8	na[a]	na[a]	na[a]	7.0
India	1064.4	308.7	29.0	822.8	238.6	29.0	1159.9	281.7	24.3	6.0
Pakistan	283.7	192.3	67.9	290.1	196.3	66.6	304.5			4.5
Cambodia	160.0	142.2	89.0	na[a]	na[a]	na[a]	na[a]	na[a]	na[a]	3.7
Congo (Belgian)	136.6	131.6	96.3	154.4	147.5	96.3	na[a]	na[a]	na[a]	3.4
Thailand	196.3	48.0	24.4	204.7	57.0	27.8	220.9	70.9	32.1	1.5
United States	2703.6	65.4	3.4	2889.7	65.8	2.3	2796.9	64.4	2.3	1.4
Uganda	52.8	52.8	100.0	55.6	55.6	100.0	61.4	61.4	100.0	
Cameroun	73.9	55.0	74.4	na[a]	na[a]	na[a]	na[a]	na[a]	na[a]	
Tanganyika	55.0	50.0	90.9	60.0	55.0	91.7	60.0	55.0	91.7	
Egypt	80.0	48.5	60.6	85.6	53.1	62.0	88.5	53.8	60.8	
Canada	1000.7	38.8	3.9	1050.6	39.0	3.7	928.6	36.6	3.9	
Japan	5505.0	40.7	0.72	5875.0	38.6	0.6	6192.5	39.5	0.6	
Peru	930.2	30.0	3.2	2000.0	30.0	1.5	3531.4	30.0	0.9	
Nigeria[b]	na[a]	na[a]	na[a]	na[a]	na[a]	na[a]	58.6	30.0	51.3	
Malaya	139.5	25.4	18.2	145.9	25.4	17.4	167.1	25.4	15.2	
Mexico	164.0	3.3	2.0	190.0	20.0	10.5	na[a]	na[a]	na[a]	
Finland	61.5	18.5	30.1	67.4	19.0	28.2	66.0	17.7	26.8	

TABLE IV (*continued*)

Area	1958			1959			1960			% of World fresh water catch 1959–1960
	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	Total catch (1000 metric tons)	Fresh water fish (1000 metric tons)	% Fresh water of total	
Sudan	19.2	18.3	95.3	na[a]	na[a]	na[a]	na[a]	na[a]	na[a]	
Philippines	447.3	17.5	3.9	517.5	17.5	3.4	467.5	17.5	3.7	
Kenya	22.4	17.5	78.1	22.5	17.5	77.8	28.2	23.9	84.8	
Netherlands	313.8	13.7	4.4	319.6	15.8	4.9	314.7	12.6	4.0	
Poland	145.1	19.5	13.4	159.7	15.3	9.6	183.9	18.3	9.9	
Italy	209.3	12.9	6.7	213.4	13.7	6.4	212.2	13.3	6.3	
Hungary	13.0	13.0	100.0	na[a]	na[a]	na[a]	14.9	14.9	100.0	
Hong Kong	69.5	21.1	30.4	67.0	13.0	19.4	62.3	12.5	19.8	
Taiwan	229.7	9.6	4.2	246.3	12.2	5.0	259.1	12.5	4.8	

[a] Figures not available.

[b] Figures for 1961.

hand, the amounts of fresh-water fish landed by various countries. As to the relative standing, parts of eastern Europe and large sectors of Africa, including the Congo (Belgian), look less to the sea. Among countries with lengthy maritime coastlines, but nevertheless largely depending on fresh-water fish, mention should be made of Pakistan and Cambodia. The latter country, according to a special monograph (Steinberg, 1957), catches 130,000 metric tons in the interior lake Tonle Sap and, furthermore, part of the fish landed off the Gulf of Siam is of fresh-water origin. The FAO figure of 30,000 tons for this country appears to require revision. A recent estimate by Bardach (1962) fixes the figure at around 90,000 tons, as the Tonle Sap no longer yields so much. Also in the Congo (Belgian) an overwhelming portion of the consumed fish comes from fresh-water, primarily the Congo River as well as a great number of fish ponds built on Belgian initiative in the postwar period.

Particularly notable is Egypt's dependency on local fish resources of the Nile and the part being played by its fresh-water resources. A number of other countries in tropical Africa, such as Uganda, Tanganyika, Sudan, are almost entirely dependent on fresh-water sources.

China is the only major country with extensive seacoast regions where fresh-water fish nevertheless constitutes a major part of the fish catch, accounting for close to half (45.3%) of its catch in 1959 (Saburenkov, 1961). This relative figure is rapidly dropping as the marine catch now is expanding appreciably under the present ocean drive of mechanized fishing fleets. About the same is true of India where fresh-water fish still accounts for approximately one third of all fish marketed, but the growth of the marine catches is also now reducing its relative importance. Sixty percent of the Chinese fresh-water harvest is cultivated (Saburenkov, 1961). Third on the list as to quantity is the Soviet Union.

The insignificance of fresh-water fishing in Japan and the United States is surprising (see Table IV); the figure for the latter is, however, somewhat misleading as a considerable amount of fresh-water fish is captured by sportsmen and in general is not included in the commercial statistics. In the drive to expand agricultural acreage Japan has reduced its lake and pond area. This intensification of agriculture and the general use of pesticides has further diminished the productivity of artificial ponds. As a whole, an intensified cultivation is taking place, with carp, "ayu," and eel as leading species, and this is reflected in a slight increase in the total amount of fresh-water fish, although it is still far behind prewar figures. The carp production has fallen drastically, partly due to spray poisoning, and is now approximately one-seventh of the production level of the 1930's (see further Volume I, Chapter 4).

When analyzed in terms of absolute quantities it turns out that two-fifths of the world's fresh-water fish are caught by the Chinese and presumably also consumed by them. Their lakes and rivers are contributing more fish as food than the marine fish used as human food in the United States. Second in rank stands the Soviet Union, accounting for 10% of the world total, but this is only a fifth of the Chinese quantity. The difficulties created in the U.S.S.R. by the present expanding industrialization without due consideration for the mounting pollution problems, and the expanded use of water for irrigation and hydroelectric purposes, are disrupting natural fish production and reducing the catch from fresh-water sources. These problems have been discussed in detail and analyzed by Borgstrom (1959, 1961b) and Ovchynnyk (1961). Several areas report declines in their catches, such as the Caspian Sea, the Baikal, etc. To some degree this has been compensated for by the raising of fish in artificial ponds and the partial utilization of man-made reservoirs.

Indonesia is a traditional fish-cultivating nation (see Drews in Volume I, Chapter 5) and accounts for more than a quarter million tons of fresh-water and brackish-pond fish. A substantial part is, however, caught in lakes and rivers. The fresh-water catch of India is of the same general magnitude, with Pakistan not far behind—each about 5% of the world's fresh-water fish.

In most other countries fresh-water fish plays an insignificant role. Consequently in the following discussion of the utilization pattern for fish it has not been considered necessary in each case to subtract the amount of fresh-water fish from the total. It should, however, be borne in mind that most of this fresh-water fish comes under the category of fresh market fish and thus slightly increases this figure in any global comparison.

Since statistical data are not available from the Chinese mainland it is not possible to include China in the following detailed anaysis. In this particular case, a separate study would have been most enlightening.

IV. General Survey of Disposal Channels

Judging on the basis of the entire world catch, the following picture emerges as to the general disposal of the aquatic harvests. About one half of the catch moves into the fresh market channel, with or without chilling. Relatively this category has shown a declining trend (see Table V), but in absolute quantities it has grown more than 5 million tons since World War II ended. Freezing and canning now take equal portions, each representing about 9% of the total in 1960, whereas curing

TABLE V
DISPOSAL OF TOTAL WORLD CATCH OF FISH AND SHELLFISH

Mode of disposal	1938		1948		1952/53		1954/55		1956/57		1958		1959		1960	
	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total	Quantity[a]	% of total
Fresh	10.3	50	9.8	51	11.1	44	12.1	44	13.0	43	14.0	44	14.9	42	15.1	40
Freezing	1.0	5	1.0	5	1.3	5	1.8	6	2.3	7	2.7	8	3.0	8	3.3	9
Curing	5.0	24	4.5	24	6.7	25	6.9	25	7.2	24	7.3	23	7.2	20	7.3	19
Canning	1.6	8	1.4	7	2.0	7	2.4	9	2.8	9	2.9	9	3.3	9	3.4	9
Reduction	1.6	8	1.5	8	3.5	14	3.6	13	4.1	14	4.2	13	6.2	18	7.6	20
Miscellaneous	1.0	5	1.0	5	1.5	5	1.0	3	1.0	3	1.0	3	1.0	3	1.0	3
	20.5	100	19.2	100	26.0	100	28.4	100	30.4	100	32.1	100	35.6	100	37.7	100

[a] In million metric tons.

accounts for about one-fifth of the catch. The fact that no changes took place in the percentage figures for India during the entire 1950's makes its figures seem highly dubious. However, the relative importance of the various alternative channels (see Table I) in broad terms, reflect prevailing conditions.

During a major part of the 1950's, 13–14% of the world catch was used for reduction into forms which only indirectly reach the human consumer as food. Due to the increased production of Peruvian fish meal this figure has shown a dramatic jump upward, and in 1961 exceeded one-fifth of the total catch. Three percent is classified as miscellaneous, chiefly for industrial uses other than food.

In several countries the utilization pattern is determined more by the composition of the catch than by the technical development. Certain species are better adapted to be preserved by one method than another. Salmon and tuna are ideal for canning. This is largely true also of the pilchards and sardines. Only 10% of the large South African catch used to be canned, the remainder going into the manufacturing of fish meal and fish oil. Presently most of the Walvis Bay catch (in southwest Africa) is canned, only offal being sent to reduction plants. Most of the Moroccan sardine catch catch goes to canning, a minor part to freezing for subsequent canning in France (Kreuzer, 1961).

It is interesting to note that on a global basis the relative amount of fresh fish has been reduced only slowly since 1938, although the catch now is 50% larger. This is explained by two trends. Tremendous improvements which have taken place in the refrigeration and icing of fish have greatly enhanced the chances of first-class handling and thereby improved the quality of the marketable fish. Numerous cases from various parts of the world could be quoted to prove this particular point. Almost all countries have acquired icing establishments, refrigerated warehouses, and refrigerated ships and holds. This will be further analyzed in Volume III, Chapter 25. Refrigerated fish carriers are being tried in warmer waters for the regular collection of catches from several fishing vessels. Such carriers operate in the Persian Gulf along a 150-mile stretch of coast in the vicinity of Abadan. On the other hand, the need for products with a longer shelf life and the important strides in the development of superior methods for freezing, curing, and canning have contributed to a vast expansion of the processing sector.

The amount of fish being processed has almost doubled, but the relative figure has grown only an insignificant 7%, from 50 to 57%. Although this is somewhat surprising, it shows the delicate economic balance between processing costs and transportation. One vital factor which might explain this lingering preponderance of fresh market fish is the fact that much of the expansion of fisheries has taken place chiefly in underdeveloped countries where fish is employed primarily to meet immediate urgent nutritional needs and consequently is consumed as soon as possible, allowing very little to go into excess production and planned storage for consumption in off-season periods. The lack of investment capital for processing is another factor limiting processing.

These observations are so far based on the total catch. It does, however, appear more satisfactory in analyzing these trends to make a clear separation between the amount of fish and shellfish being utilized as human food and those quantities being directed into reduction plants.

Table VI summarizes the result of such an analysis limited to the food fish. A somewhat modified picture then emerges of the relative decline in the amount of fish being utilized as fresh. Yet in the final result more than half of the world's fish catch is presently being eaten fresh, although the processing portion is rapidly reaching the 50% level. As it has in most other food commodities, the most rapid growth is in the freezing sector; second comes canning. In spite of this advancement in alternative methods, curing still accounts for more fish than freezing and canning combined.

The most spectacular industrialization in the fish field has occurred in Peru. As late as 1939 this country had one fish-processing plant, installed in Pisco. Presently there are more than 120 plants, employing more than 10,000 and chiefly located in Callao, Lima, and Chimbote. In 1960 the production consisted of 1.7 million cases of canned fish, 18,000 metric tons of frozen fish, 550,000 metric tons of fish meal, and 48,000 metric tons of fish oil. A major portion of this is exported (see Section XX).

It is, nevertheless, a most noteworthy fact that fresh market fish between 1953 and 1960 increased in volume no less than 4.3 million metric tons. This is, in effect, almost 40% above the total amount either frozen or canned in the entire world.

Most utilization figures in individual countries show an appreciable fluctuation from year to year. One characteristic feature of fishing is, after all, the effect that weather vagaries and biological conditions have on catch, resulting in poor and good years. In many countries the processing industry is not organized to handle unusually large quantities, and the excess is then generally moved into the reduction plants; for this reason the figures in such countries show considerable fluctuation. These variations become less accentuated when the buffer lot, represented by what enters reduction plants, is subtracted and the analysis is made on the remainder of the fish, the bulk of which is largely moved into the field of human food. The amount of such food fish is, in effect, a far

TABLE VI
PERCENTAGE DISTRIBUTION OF WORLD CATCH INTO VARIOUS DISPOSAL CHANNELS

	1938	1948	1952/53	1954/55	1956/57	1958/59	1959	1960
Total catch (million metric tons)	17.9	16.7	21.0	23.0	25.3	29.2	30.6	29.3
Mode of disposal (%)								
Fresh	57.5	58.7	52.8	52.5	51.7	53.1	53.6	52.0
Freezing	5.7	6.0	6.0	7.8	9.2	9.8	10.0	11.7
Curing	27.9	26.9	31.7	29.8	28.6	26.6	25.0	24.9
Canning	8.9	8.4	9.5	9.8	10.6	11.1	11.4	11.9

more stable amount, chiefly due to the fact that market demand does not change precipitously from year to year.

It should, nevertheless, be borne in mind that in countries with poorly developed cold chains the catches do not always reflect the actual consumption. In season, gluts are common and the market gets saturated; much "fresh fish" is lost through spoilage prior to reaching the consumer. De Felipe (1959) estimates that 10% of the Mediterranean catch and 20% of its value is lost through lack of adequate refrigeration facilities on board or on shore. The preservation capacity is, outside of simple salting, not adequate.

The term "food fish" has been employed in the table headings and text of this study, although it is recognized that in some countries, such as the United States and the United Kingdom, some of this fish belongs to the category of pet food and bait. In cases where this is a substantial factor, it is indicated in the tables that the fish belong to a special subgroup, according to official statistics. These lots are, however, subject to large variation, although not to the same extent as fish used for reduction purposes.

V. Remote Fishing

Distant fishing operations, remote from the ship-owning countries, have become a most significant feature of world fisheries in the postwar period. For centuries the Great Banks fisheries conducted by European fishermen from Portugal, Spain, France, and the United Kingdom belonged to this category. Nowadays a great number of additional countries have joined these operations.

The two most expansive undertakings in distant fishing are the large-scale operations by Soviet and Japanese fleets in almost all oceans.

A. Soviet Expansion

Murmansk and Kaliningrad are the bases for Soviet North Atlantic operations covering the Newfoundland Banks, Davis Strait (off West Greenland), Sea of Norway, the waters off Iceland, the Faeroe Islands, the Hebrides, the Orkneys, and the Shetlands. Sizeable catching flottillas provided with floating factories, carriers, and some other specialized fish-searching vessels regularly visit these regions. Also Soviet fishermen are found regularly in waters off the New England coast (Georges Bank), Bristol Bay, the Gulf of Alaska, the Aleutian Islands and off continental Alaska (Yakutat), and around the United Kingdom. The Sea of Okhotsk is largely being developed as a Soviet water nowadays, with only a few Japanese fleets and floating factories allowed. The Bering

Sea is systematically scanned and increasingly fished by the Soviet flotillas. In most cases these large-scale commercial operations have been preceded by extensive oceanographic and fisheries reconnaissance by various types of Soviet research vessels. This is also true of the similar, regular fishing operations off the coast of tropical Africa from Agadir and Dakar in the north, down to the Gulf of Guinea. Most of these catches are brought to Cherzon in the Black Sea and to Kaliningrad, frequently for further processing (for additional information see Borgstrom, 1961a).

These Soviet fisheries have now been extended southward to include major operations off southwest Africa, particularly at Walvis Bay, and in the waters off South Africa, trawling for pilchards and various whitefish. Red Sea operations have been initiated by Soviet flotillas, even in this case after previous oceanographic and fisheries reconnaissance. Tuna fishing in the tropical regions of the Pacific and the Atantic are being planned by the U.S.S.R.

B. Japanese Endeavors

Japanese fishing has taken on an equally global nature. Several new fishing grounds have been developed in the Pacific, the Indian Ocean, and off Madagascar. Both Brazil and Argentina are building their Atlantic fisheries in close cooperation with Japanese fishing companies. The Mediterranean fishery is becoming dominated by Japanese operations on the basis of a series of bilateral agreements with most of the Mediterranean countries: Italy, Yugoslavia, Greece, Israel, Egypt, Morocco, etc. Independent Japanese fishing is carried out off the coast of Tripoli. Japanese tuna vessels roam the tropical Atlantic, with a main base in the Canary Islands. (As to Japanese bases in the Caribbean and on the African coast, see Section XV.) In 1960 Japanese trawlers participated in the Icelandic herring fishing. Mention should also be made of the Japanese tuna bases off North Borneo, in the Fiji islands, and on Madagascar. In Section VI mention is also made of the Japanese penetration into the Bering Sea with large floating fish-meal factories and extensive crab operations.

These long-range operations have had a considerable impact on the utilization pattern. Fresh market fish—unless defrosted from bulk-frozen fish—is excluded under these conditions. Statistics are too scanty to appraise the degree to which distant catches are landed in foreign ports. Japan reports that of their 1958 tuna catches, 10.5% was landed in foreign ports. Only minor quantities have been sold to adjacent African ports by Soviet fleets fishing off the Atlantic coast of tropical Africa.

C. OTHER COUNTRIES

Poland, in the latter part of the 1950's, expanded its fishing into the North Sea and the northwest Atlantic, and also into more distant waters off tropical Africa (see Table VII). The absolute catch taken in these remote areas has more than tripled, and in relative terms it has grown from 24.6% to 48% of the total. Most of the capital improvements made in the West German fishing fleet refer to such remote fishing (Meseck, 1959). The significance of long-distance fishing to West Germany is best elucidated by the fact that out of 282,612 metric tons landed by trawlers in 1962 no less than 189,000 metric tons came from the waters off Iceland and Greenland (Pêche Maritime, 1962). East Germany nowadays participtates with large processing vessels in the fishing off Newfoundland and Greenland.

TABLE VII
FISH CATCHES OF POLAND, 1954–1959[a]
(1000 METRIC TONS)

	Marine			
Year	North Sea and distant waters	Baltic Sea	Fresh water (lakes, rivers, and ponds)	Total
1954	29.0	70.4	18.5	117.9
1955	41.7	65.6	19.6	126.9
1956	49.0	73.5	16.8	139.3
1957	53.3	72.4	13.1	138.8
1958	60.2	67.5	17.3	145.0
1959	76.6	69.6	13.5	159.7

[a] Source: Kordyl, 1962.

Seventy percent of the Portuguese fish catch is secured from African waters, off Cape Branco and adjacent regions. Large investments have been made in modern rapid diesel-driven trawlers equipped with refrigerated holds. Still more such ships are being built (Houk, 1961).

VI. Floating Factories

A. GENERAL

One unmistakable trend of the postwar period has been the transfer of the processing operations onto the seas and thereby into distant waters. The modern vessels combining catching and processing have greatly expanded the range and efficiency of fishing. To this category belong the Soviet freezing trawlers and crab-canning ships. A slightly different operational pattern is represented by the motherships, which keep the catching and processing functions separate. This is analyzed by Borgstrom (1959, 1961b, e) and Hardy (1961).

The Soviet Union has led this development in a big way. The Soviet Bloc as a whole is following suit and building up its sea processing potential. A number of new freezing trawlers are on order by Poland, East Germany, Yugoslavia, and China. Even Bulgaria is acquiring processing factories to operate in the Black Sea.

In the 1960's a number of western countries began entering into this race, and in several cases on a sizeable scale. The United Kingdom, who pioneered this development by its "Fairtry" experiments in the 1930's and 1950's has recently put in operation "Lord Nelson," owned by a private company. The American "Pacific Queen" conducted similar experiments in the immediate postwar period. The United Kingdom is also experimenting with using outmoded aircraft carriers as processing motherships at sea. France, Spain, Portugal, Italy, and Greece are all acquiring modern freezing trawlers, chiefly of Soviet stern-trawling type, but larger than the "Puskins" (approximately 2400 tons).

West Germany now has 19 distant-water part-freeze trawlers in service with its fishing fleet, incorporating not only the latest in fishing vessel propulsion but also filleting and processing lines more in keeping with full-scale factory ships than with 210-ft. trawlers. By the middle of 1962 there will be 35 such West German trawlers in operation. Ocean perch (redfish) constitutes more than 70% of the West German marine catch.

To ensure regular and adequate supplies of fresh herrings for the production of quick-frozen kipper fillets in the United Kingdom, a medium-size trawler, "Autumn Sun," has been equipped for freezing and for low-temperature cold storage. The principle of operation is that this boat follows the movement of the herrings, and is docked at the port nearest to the seasonal fishing grounds. Here the trawlers deliver their catch only a few hours after capture, and freezing takes place almost at once. The same principle is applied to other fish that are subsequently to be processed by canning or other means, ranging from pilchards at Looe in Cornwall to whiting at Ayr.

The full cargo of the "Autumn Sun" is, in terms of such frozen fish, 80 tons. As soon at it is fully loaded the boat sails for Great Yarmouth, where the frozen slabs are unloaded and either processed immediately or stored for subsequent withdrawal in batches for processing (Hammond, 1960). (For a comprehensive discussion of processing at sea, see Volume III, Chapter 25, by Jul.)

A few significant trends in this field with regard to fish utililization will be discussed here. It should, however, be observed that American tuna ships early acquired freezing wells to preserve their catches and allow hunting in distant waters. This might be termed a kind of preprocessing or semipreservation later to be followed by a final manufacture.

On the whole the development of off-shore processing facilities have almost eliminated the need for placing shore facilities for final processing close to any fishing grounds. This factor once determined the location of, for example, the West German fish-processing plants. Any readily attainable port can now be selected.

Another interesting consequence of processing at sea is circumvention of the auction system of selling fish, which in most countries is so detrimental to quality, as well as hampering speedy delivery. The general increase in activity to make fishing more efficient has been facilitated by the simultaneous creation of local processing facilities at sea. It is to be assumed that this improved efficiency otherwise would have had detrimental effects on the keeping quality of the fresh market fish.

B. Freezing Trawlers

A potential rival to the factory trawler and the freezing trawler—two main lines of development being pursued in the British fisheries industry—is the mothership, which processes the catch of a fleet of fishing vessels. In such a unit the output required for economic operation has to be matched to the number of catchers employed. The areas of ocean over which the fleet may be scattered at various seasons and places also has to be determined. Important too is the method of transfer. Even if fish is collected from the catcher every 12 hours or less, it will be necessary to take a good deal of trouble to handle and chill the catch properly, both in the catcher and in the collecting vessel.

As to more recent developments on this rapidly changing sea front, a few notable acquisitions, innovations, and accomplishments may be reviewed.

Quick freezers are presently being installed on all Soviet deep-sea trawlers. The old herring motherships are being refitted with high-speed vacuum-canning lines as well as fish meal plants. According to *Fishing News,* in 1961 a Volga shipyard was building, for service in the Caspian, a 3500-ton floating factory to be 275 ft. long, with a 60-ft. beam, and largely built of reinforced concrete. A 10,000-ton diesel-type freezer, the "Sevastopol," is able to freeze 100 metric tons of whale blubber or fish per day. It is based at Odessa in the Black Sea. In season it serves the Antarctic whaling fleet, and the remainder of the year, various fishing fleets (Petrov, 1960).

A French-built factory trawler equipped with facilities for evisceration and filleting, the "Jeanne d'Arc," is based in Boulogne. Its refrigerated hold has a volume of 1200 cu. ft. The vessel has a speed of around

14 knots. It is fitted for starboard fishing only. Gross tonnage is around 500. From British shipyards four purse-seiners and two stern-trawlers have been delivered to Ghana (April, 1962). The freezing trawlers are equipped with blast tunnels. These vessels form the nucleus of Ghana's state-owned fishing fleet.

Spain has acquired three large, distant freezing trawlers: "Andrade," "Lemos," and "Pambre." They have reported excellent results from their first catching and processing trips (Anonymous, 1962b). They have operated in Antarctic waters, off Argentina, and off the Cape of Good Hope in the Table Bay area. The chief catch was South African cod with an average size of 3–5 kg., occasionally reaching the size of 3 ft. and a weight of 7–8 kg. The distance to the South American fishing grounds is almost 2000 miles farther than to the South African waters (4000 miles). The British are contemplating the creation of permanent fishing bases with processing facilities on the Falkland Islands.

Greece now owns 13 modern freezing trawlers, and 5 more will be delivered during 1962. Their Atlantic fisheries, as a consequence, has grown from a trifle to 8000 metric tons in 1960 and 14,500 tons in 1961. Their chief fishing ground is off the coast of Mauritania. Italy also has acquired modern freezing trawlers for the development of their Atlantic fisheries.

Japan, too, is provided with a number of large freezing trawlers, built in the postwar period, as part of their drive to expand to high-seas fishing, as well as remote fishing in general.

C. Floating Canneries

Floating canneries preceded the present freezing trawlers. They were used early by the United States in Alaska. These vessels were equipped not only for canning but also for waste processing. They were, however, land-based.

Japan started to move out to high-sea fishing grounds as early as the 1920's, and later entered into competition with the Soviet Union by catching and processing off the Soviet Pacific Coast. Soviet salmon canneries on shore at the mouths of the rivers were partly deprived of their raw material, due to Japanese operations at sea. This was behind the naval skirmishes in the 1930's.

Both the U.S.S.R. and Japan now operate several floating canneries primarily for herring and salmon. Canning lines are presently being installed on the Soviet herring mother ships. A large (14,000 gross tons) fish- and crab-processing vessel has been built by the U.S.S.R. for operation in the north Pacific region. Egypt is acquiring a floating cannery.

A new feature are the large Japanese shrimp-canning vessels (7400 gross tons)—each with a fleet of ten trawlers. Peelers belong to the processing equipment and allow the manufacture on board of a final ready product.

D. Barges

An intermediate step, using barges towed up and down rivers and along the coastline, was introduced by the Russians on the Volga at the beginning of the 19th century. These were built for bulk freezing in ice mixtures. The canning industry in Alaska used barges equipped for canning in operation for a great number of years, whenever catches did not justify shore installations (see further Borgstrom, 1961). Refrigerated barges to be used in salting have recently been introduced on the river Kuskokwim, north of Bristol Bay. Towed freezers are operating on the Yukon river (Pacific Fisherman, 1962).

Floating fish factories may in general be the solution for coastal regions deficient in transportation and industrial equipment. Such floating canneries have been tried along the coast of Gambia and up the Gambia River. Sharks are common in these waters, and subject to capture and marketing.

E. Salting Units

Salt herring is one of the oldest products to be processed at sea. It is still landed in appreciable quantities in most northern and western European countries by ordinary trawlers and deep-sea cutters.

Cod salted at sea also has a long history, and constituted the basis for the development of the Grand Banks fishery (see page 17). France, Portugal, and Spain are dominating this scene.

Large factory ships, designed to serve as motherships for the Soviet herring fleet, have been built in Polish shipyards. They will replace the present mother ships which were converted from cargo ships and are considered outmoded. This is the first known effort to build specialized ships to serve these purposes (Staszewski and Pazkowski, 1959). This new type of mother ship is equipped to process the catches supplied by fishing vesels and to deliver ashore lightly and moderalely salted herring. These ships are designed for large-scale fishing operations in the northern parts of the Atlantic and the Pacific (Terent'eva, 1958). A large mother and factory ship (17, 000 displacement tons) has been reported (1962) to be operating with the herring fleet out of southern Sakhalin in the Far East.

Each of the new motherships will be able to produce 35,000 standard 120-liter barrels of finished product per trip, and to supply continuously 70 medium trawlers-drifters with empty barrels, salt, fuel, fresh water, food, and fishing gear. The new ship will be able to receive catches simultaneously from 4 fishing vessels. The capacity of the factory ship's processing plant is plannned to be up to 200 tons per day; a possibility of deliveries up to 400 tons per day is foreseen. In the latter case, 50% of the catch delivered aboard will be sent to the processing plant while the remainder is stored. The processing plant is fully mechanized, has one production line, and is manned by 58 workers—as against 170 in the case of nonmechanized production. The mechanized packing will enable 110 kg. of procesed herring to be packed into one barrel, as against 90 kg. with manual handling. Production costs for herring processed on board these motor-factory ships is 10% lower than for herring processed ashore (Terent'eva, 1958).

F. FACTORY AND MOTHERSHIPS IN GENERAL

Two Japanese motherships—one of 5500 tons and one of 3000 tons —with accompanying fishing fleets were operating in the waters south of the Aleutian Islands in the winter of 1961-1962 (Western Fisheries, 1962b). Other factory ships are in the western reaches of the Gulf of Alaska.

A number of vessels designed for fishing and processing in tropical waters, largely air conditioned ships of the "Tropik" class, have been developed and built by the Soviet Union for fishing the tropical Pacific and Atlantic (Ishkov, 1962).

The Soviet Union claims to own the most advanced factory ship ever built, the "Andrei Sakharov." It was delivered in 1961 from East German shipyards at Rostock. The processing is highly automatized—almost completely, in fact. A special device allows separation between large and small fish and mechanized chilling operations. The vessel is equipped with sardine dryers, automatic oil extractors, an ice-making plant with a capacity of 25 metric tons per day, and a carton-folding machine. This ship is presently operating in the Red Sea and the Indian Ocean (see *World Fishing*, July 1961).

The large Soviet factory ship "Vladivostok" (14 knots, 1700 tons, 408-man crew) built to order in West Germany, is part of the Soviet Antarctic whaling fleet (see Section XIX). It engages in extensive fish meal operations, but is basically a freezing plant. The holds for frozen fish have a capacity of 3200 cubic meters (m^3), those for finished fish meal of 4400 m^3, with additional tanks for oil of 1100 m^3.

West European and Japanese shipyards are reported to have orders for 25 motherships and two whaling ships (13 of which are 8000 gross tons each; the remainder 20,000 gross tons each) for delivery to the Soviet Union by 1965. No less than 66 factory ships are reported under construction in Stralsund, East Germany. They are intended for fishing in tropical waters. Each has a frozen fish capacity of 500 tons and will be equipped to manufacture 60 tons of fish meal (Anonymous, 1961c).

Poland is building a whole new series (B-20) of processing trawlers (dwt. 500 tons) with freezing and salting lines for the North Atlantic and North Sea.

G. Transporting Vessels

Transfer at sea to carriers has become a regular feature of Soviet operations (Borgstrom, 1961a). The most recent Soviet acquisition is a new series of 2500-ton dwt., 15-knot, diesel-driven, refrigerated carriers of the "Tavriga" type for operation in tropical waters (Anonymous, 1961).

Egypt has on order refrigerated carriers to bring home catches from distant waters (*Fishing News,* Jan. 19, 1962).

H. Fish Meal Factories

A new feature in processing at sea is the launching of large floating factories which specialize in the manufacture of fish meal. Japan is leading in this development. Several major units—at least seven—were sent to the Bering Sea in 1960 and 1961.

At the start of 1962 one large vessel of this sort, the "Ronshin Maru" (14,094 BRT), was operating off the coast of Angola. Its capacity is 100 metric tons per day. In the period from December to February, 7300 metric tons of fish meal was manufactured on board. Two Japanese fishing vessels and several from Angola took part in the catching. One third of the production was sold to Angola.

I. Fishing Vessels

Another trend noticeable in most countries is the increase in size of the fishing vessels to ensure greater economic efficiency. But essential to such efficiency, as mentioned previously, has been the simultaneous expansion in processing facilities at sea, as well as on shore.

Soviet experimental work has clearly shown the advantages of such larger vessels. Of the total Soviet catch in 1960, 76% was taken with vessels exceeding 300 hp. but not constituting more than 6% of the fishing fleet in numbers. Heavy vessels took a catch of 3800 lbs. per hp. per year and 76,000 lbs. per crew member. Vessels below 300 hp. took 2690 lbs. per hp. per year, and 19,000 lbs. per crew member (Ishkov, 1962).

A middle-sized trawler of the so-called "Atlantik" class has been designed for herring netting and midwater trawling. A vessel specially designed for the Pacific fishing of saury, tuna, and shrimps has been developed by Soviet experts (Ishkov, 1962).

VII. Fresh Market Fish

A. GENERAL

It is noted that the term "fresh" is ambiguous with regard to fish and should, if possible, be abandoned. The word "fresh" has many meanings (see Borgstrom, 1963a), not the least in connection with fish, primarily meaning one of the following: (1) raw, (2) non-spoiled, or (3) non-processed, as against frozen, canned, etc. Owing to this, the term "fresh market fish" has been adopted in this presentation.

When studying the individual methods of preserving fish and the channels for its marketing, it has been customary to base the comparisons between countries on the relative standing of each individual method. Very little attention has been given to the total quantity of a country or whether its fish utilization is characterized by other important procedures. It is one thing if a country shows a high degree of reliance on one particular method of utilization, but quite another matter is the amount of the total catch, and relative to that, the absolute amounts of fish being channeled via the various procedures.

B. UTILIZATION PATTERN

On the basis of the proportion of fish being taken care of by the fresh market, Italy is ranking first, with Ireland and the United Kingdom second and third (see Table VIII). Analyzing the list further, it is evident that among the countries with a high percentage of fish moving into the fresh market are many with a poorly developed cold chain but compensated by short distances from coastal areas to major consumption centers. Into this category the following countries fall: Greece, Pakistan, Turkey, South Korea, Chile, and possibly Spain. A second group is characterized by well-developed cold chains and an extensive network of refrigerated warehouses. In this category may be listed: United Kingdom, Belgium, Australia, Finland, and Denmark. The naturally cool climate of Finland, with few days of high temperature even in the summer, also contributes to facilitating distribution of fresh market fish. Something similar applies to Ireland most of the year.

When analyzed on the basis of total amount of fish marketed in an unprocessed form (see Table IX), China is clearly leading the field, but no recent statistics are available. It can be estimated that at least 2 million metric tons are marketed there in this form. In the second place comes Japan (1.40 million metric tons in 1960), accounting for some 9% of the world's total fresh fish. Third is the United Kingdom with some 6%. The fresh market fish in the United States amounts in volume to less than half that of Japan. As far as is known, Tokyo, with a population of 9.75 million, has the world's major fish market, consuming some 1600 metric tons of fish per day. It is located at Tsukijim, the southern part of the city, facing Tokyo Bay. It covers 50 acres and is the largest in Asia. There are five ice rooms capable of storing up to 9000 metric tons of fish. About 4000 tons of water and 250–400 tons of ice are used per day.

TABLE VIII

PERCENTAGE UTILIZATION OF FRESH MARKET FISH AND SHELLFISH (1960)

	Fresh market fish			Fresh market fish	
Area	Percentage of area's food fish	Percentage of area's total fish	Area	Percentage of area's food fish	Percentage of area's total fish
Italy	86.1	86.6	Netherlands	52.7	47.5
Ireland	85.4	83.4	India	52.3	47.9
United Kingdom	84.3	79.8	United States	45.9	30.0
Colombia	84.0	74.1	Peru	42.3	2.3
South Korea	83.2	82.4	West Germany	43.0	35.1
Indonesia	80.0	80.0	Venezuela	39.4	39.4
Belgium	79.5	77.1	South Africa[b]	37.4	19.8
Pakistan	75.6	71.8	Canada (excl. Newfoundland)	31.1	22.0
Turkey	73.9	72.7	Japan	26.4	22.6
Finland	70.1	65.8	Newfoundland	24.4	2.2
Spain[a]	69.8	65.9	Canada	23.3	20.6
Chile	66.8	24.7	Faeroe Islands	22.2	22.1
Australia	65.6	64.7	Norway	21.1	10.8
Greece	62.8	62.8	Morocco	20.4	7.7
Philippines	62.1	62.1	Soviet Union	17.4	15.5
France	60.2	55.8	Iceland	9.6	7.8
Denmark	56.0	22.7	Portugal	7.7	7.7
Argentina	54.4	51.7			

[a] Figures for 1958.

[b] Figures for 1956.

Some 15 million tons, or about 40% of the total world catch, is thus sold raw to the consumer. This group contains quite a variation as to species. The type of product varies too. There is, however, a major shift towards filleted fish. Normally, supplies of fresh fish are subject to considerable fluctuations, due in turn to variations in the fish catch and landings. Fresh fish supplies consequently are never too regular. The reduction industry frequently is prepared to take care of the surplus quantities in order to minimize sharp fluctuations in supplies and prices. Improved methods of capture, handling, and transporting, particularly with the use of ice, has greatly widened the radius for distribution of fresh fish. On the other hand, the need for extended fishing trips far from coastal areas of the homeland naturally has contributed to the diminishing importance of fresh fish and will continue to reduce its significance in the future. Here, however, statistical discrepancies, mentioned above, come as a complication.

TABLE IX

QUANTITIES OF FRESH MARKET FISH AND SHELLFISH (1000 METRIC TONS)

Area	Average, 1953–1955	Average, 1956–1958	1958	1959	1960	Percentage of world total, 1959–1960
World	11,433	13,333	14,050	14,900	5,100	100
China	na[a]	na[a]	na[a]	na[a]	2200	14.6
Japan	1648.4	1533.7	1379.5	1414.9	1398.7	9.4
United Kingdom	893.5	926.7	917.8	903.3	854.5	5.9
United States	788.8	736.4	730.3	727.1	838.7	5.2
Spain	427.0	481.2	551.0	na[a]	na[a]	3.9
Soviet Union	400.0	412.0	425.0	450	480	3.1
India	354.1	471.1	454.5	351.3	555.6	42.1
Philippines	214.8	267.5	277.1	329.5	295.5	
France	301.1	304.3	312.1	305.2	314.0	
West Germany	na[a]	na[a]	260.0	261.0	261.0	
South Korea	199.9	243.8	218.3	223.1	282.2	
Pakistan	na[a]	na[a]	213.9	215.0	218.6	
Canada	172.2	179.4	189.6	215.2	188.6	
Italy	182.2	184.5	181.4	186.0	184.2	
Norway	191.4	197.0	177.6	184.4	172.4	
Netherlands	125.5	137.2	152.1	147.3	165.3	
Denmark	105.1	103.5	90.7	105.6	132.2	
Peru	38.0	53.3	61.5	80.0	80.3	
Turkey	70.9	86.1	83.2	70.3	na[a]	
Chile	73.9	90.3	87.3	67.3	na[a]	
Greece	46.8	na[a]	na[a]	62.8	na[a]	
South Africa	67.3	59.7	na[a]	na[a]	na[a]	
Argentina	42.9	38.9	40.4	47.5	52.2	
Finland	47.2	44.5	43.3	44.8	43.4	
Australia	37.3	36.4	36.1	37.1	39.3	
Venezuela	21.4	27.1	28.0	32.8	na[a]	
Ireland	17.0	27.1	29.4	27.5	35.7	
Iceland	14.5	20.0	17.3	24.7	46.0	
Belgium	54.5	na[a]	na[a]	18.3	40.5	
Portugal	65.1	48.1	17.8	16.0	17.5	
Faeroe Islands	6.6	8.8	13.0	15.2	24.2	
Colombia	na[a]	13.2	16.7	14.2	22.0	
Poland	19.6	15.7	17.2	13.5	na[a]	

[a] Figures not available.

Growing amounts of fish are being frozen at sea, brought ashore, defrosted, filleted or prepared, and then distributed. The procedure of allowing defrosting during the distribution and retailing as fresh, e.g., in deliveries from Grimsby to various parts of England, is a special variation of this procedure. Similar methods are presumably employed in several countries, although not generally publicized.

Some new fisheries, comprising species not earlier figuring in the catch statistics, add to the fresh-market fish section. Such an example is the char of the Canadian Eskimo. More than 50,000 lbs. are presently sent to restaurants in Montreal, Chicago, Toronto, and New York as a special delicacy.

C. Filleting

The Western trend toward a growing percentage of the catch being filleted is most evident in the United States, Canada, and Western Europe. West Germany reports that more than three-fourths of their catch is filleted at the markets by wholesalers (Hass, 1961).

Efforts to promote fresh fillets of cod have failed in Spain (Lopez Capont, 1961). The traditional "bacalao" is so well entrenched in the popular estimation that Spain in this respect constitutes a unique exception to a trend otherwise dominant in almost the entire world. Almost all cod in Portugal is dried prior to marketing even when landed as fresh.

D. Investments

Investments required for processing used to limit any elaborate preservation of the fish. Nevertheless, in most cases the losses incurred by large-scale spoilage, particularly in glut periods, were not taken into account, for example, in Korea. In other cases markets became very limited in space, as is the case in the fishing ports of Portugal—Lisbon and others—or in the coastal areas of Morocco. When weighing such limitations it soon became evident that substantial investments were justified also in the fresh-market fish sector. A number of countries have in the postwar period invested in icing establishments and other shore installations for chilling. This is reported from Murmansk (USSR), most of the Baltic fishing ports of Poland (Anonymous, 1960), the Belgian Congo during 1948-1954 (Anonymous, 1961a), several East Indian ports, at Haifa in Israel, the new harbor of Tema in Ghana, etc.

In many cases these investments have reached such a magnitude than it seems probable that corresponding installations for complete preservation would have been more advisable than resorting to traditional procedures and putting so great an effort in what always will remain a short-range preservation. Some chilling capacity is nonetheless necessary for the maintenance of quality prior to processing, but this can be on a more restricted scale and with a smaller capacity.

The large-scale investment during the postwar period in larger and more efficient fishing vessels constitutes a trend working toward stabilizing, improving, and expanding the fresh market distribution of fish. Motorization and higher velocities of vessels are other factors having a similar effect.

A number of the new African countries are launching into greatly expanded fisheries and venturing into new motorized fishing vessels. Trawlers from the Congo (Belgian) operate in waters off the southern coast of Angola and the catch is brought up the river Congo to Matadi; these trawlers have been provided since 1951 with modern icing and handling installations. Distribution methods have also improved by the use of specially insulated boxes partly filled with crushed ice (Anonymous, 1961). In the Belgian Congo the fish used to be dispatched this way to Leopoldville and other major population centers.

E. Miscellaneous

Several new types of packaging have been introduced in many countries and put to successful practice test. Surface treatment of wooden boxes and the use of aluminum boxes diminish bacterial contamination (see further Volume III, Chapter 7).

Transportation of fresh fish by air is coming to the fore in several parts of the world, bringing fish from Scandinavia to different European cities; from coastal fishing regions of Canada to the interior, particularly Montreal; taking shrimps to the United States from distant sources such as India, Hong Kong, etc.

Some fresh market fish are sold alive (see Chapter 1, Section III, 2); this method is still in use along the Norwegian coast. Transport vessels equipped with live wells bring the catch to shore (Angerman *et al.*, 1961). On the island of Åland in the Baltic, fish used to be held live in holds kept in the water. Icing is now substituted for this traditional method, which is gradually vanishing.

One essential feature is also the providing of fishing vessels with refrigeration facilities, allowing the carrying of ice to sea, a rapid chilling of the catch, and the keeping of fish in cooled holds. For a time there was an effort rather to speed up the velocity potential of fishing vessels. Most studies and practical experiments point to chilling as a cheaper alternative.

Several million pounds of fresh fish reach the consuming British public via fish and chip shops. This institution has largely contributed to a strengthening of the fresh-market sector in the United Kingdom.

These shops can also be looked upon as local, centralized cooking installations, partly contributing to a lengthened shelf life through cooking.

In many parts of the globe cooking does play a part in the preservation and keeping of fish.

VIII. Curing, Smoking, and Drying

A. GENERAL

Second to fresh market fish in importance are the cured products—salted and dried taken together. Percentage-wise, curing dominates the utilization scene of Portugal, the Faeroe Islands, Norway, and Japan (see Table X). In India sun-dried fish accounts for 25.9% and salt-dried fish for 24.8%. Besides India, both Norway and Japan submit approximately half their food fish catch to curing. In all these cases salting and drying have been the traditional methods for securing vital animal protein and making it available throughout the year. Such traditions go back many hundreds of years. The salted fish is primarily herring, and the fish chiefly employed for drying are ling, cod, and haddock.

TABLE X

PERCENTAGE UTILIZATION OF CURED FISH (1960)

Area	Percentage of area's food fish	Percentage of area's total fish
Portugal	92.3	92.3
Faeroe Islands	73.2	72.9
Newfoundland	58.7	53.0
Norway	52.4	26.8
Japan	50.9	43.6
India	47.7	43.7
Iceland	38.2	31.1
Philippines	37.9	37.9
Canada	34.9	30.8
Soviet Union	33.9	30.2
Netherlands	32.2	29.0
South Africa	29.2	15.5
Turkey	24.6	24.2
Canada[a]	24.4	17.3
Pakistan	23.8	22.6
France	23.7	23.7
Venezuela	20.9	20.9
Indonesia	20.0	20.0
Spain	19.4	18.9
West Germany	18.1	14.8
Colombia	16.0	14.1
South Korea	14.1	14.0
Greece	13.0	13.0
Ireland	12.9	12.6
Finland	12.2	11.5
Peru	11.3	0.6
Denmark	6.4	2.6
Belgium	6.2	6.0
Italy	6.2	6.2
United Kingdom	2.7	2.6
United States	2.0	1.3
Argentina	0.84	0.80
Chile	0.29	0.10

[a] Excluding Newfoundland.

In terms of all fish, not excluding industrial fish, only one major change is observed in the rank order. The relative place of salting and drying becomes lower in Norway. The proportion of cured fish declines from 57.9% to 31.6%.

When analyzed from the point of view of quantities, Japan far outdistances any other country, accounting for 37% of all salted and dried fish (see Table XI). In second place comes the Soviet Union with 14%, followed by Norway (7%) and India (6%). Although early American Indians traditionally dried and smoked fish as an important item and a mainstay in their diet, this method plays a very insignificant part in the United States today.

TABLE XI
QUANTITIES OF FISH AND SHELLFISH UTILIZED IN CURING
(1000 METRIC TONS)

Area	Average, 1953–1955	Average, 1956–1958	1958	1959	1960	Percentage of world total, 1959–1960
World	6617.0	7233.0	7300	7200	7300	100
Japan	2124.1	2504.6	2670.5	2716.6	2700.4	37.4
Soviet Union	na[a]	na[a]	na[a]	983.0	na[a]	13.7
Norway	443.2	529.1	502.0	507.5	427.9	6.5
India	420.2	559.3	539.6	417.2	506.9	6.4
Canada	292.5	257.3	204.8	259.6	281.5	3.7
Philippines	136.8	155.6	169.7	187.2	180.3	2.7
Iceland	222.5	218.9	197.6	178.7	184.5	2.5
Portugal	203.9	209.1	179.4	159.6	185.3	2.3
Spain	174.8	187.2	158.2	na[a]	na[a]	2.2
France	144.9	147.4	146.1	123.2	123.4	1.7
West Germany	na[a]	na[a]	109.0	109.0	110.0	1.5
Netherlands	123.9	98.3	95.9	91.2	91.3	1.3
Faeroe Islands	88.7	97.7	90.2	69.1	79.7	82.9
Pakistan	na[a]	na[a]	56.6	61.1	68.9	
South Korea	44.0	61.7	66.5	59.5	48.0	
South Africa	49.3	47.7	na[a]	na[a]	na[a]	
United States	34.3	39.3	38.6	28.8	37.2	
Turkey	26.2	116.7	5.4	23.4	na[a]	
Venezuela	27.4	22.1	18.1	17.4	na[a]	
Peru	6.2	12.2	14.6	15.0	21.9	
Italy	21.8	19.2	15.1	14.3	13.2	
Denmark	11.4	13.0	14.1	13.1	14.9	
Greece	0.9	9.4	12.8	13.0	na[a]	
Belgium	9.5	na[a]	na[a]	12.0	3.0	
Finland	9.6	8.2	7.6	7.6	7.6	
Ireland	1.9	4.0	5.1	6.2	5.4	
Argentina	2.5	5.7	6.3	6.0	0.8	
Colombia	8.2	10.5	5.8	3.8	4.2	
Chile	0.9	2.0	2.6	0.3	na[a]	

[a] Figures not available.

B. DRYING

Norway is the only country producing stockfish, which is made from ling, cod, and other codfishes, and is dried only by sun and wind without prior salting. Klipfish is a more elaborate product, nowadays partly submitted to artificial drying. The cod is previously split and salted. Iceland also produces dried cod in quantities, and so does Japan. Almost the entire stockfish production is being exported, the principal markets being Italy and West African territories. This item is the most concentrated animal protein available on the world market.

Portugal accounts for close to 65,000 tons to dried cod and seems to be the leading nation in the manufacture of this product. Yet more than 20% of the Portuguese consumption of this item has to be imported. Almost all cod is dried prior to marketing and consumption, as is the case in Spain (Lopez Capont, 1961).

Due to the opening up of the extensive markets of the malnourished in Latin America and tropical Africa, the demand for dried fish is mounting considerably. This is reflected in the increasing percentage of the Norwegian catch going into dried products since 1954, presently approaching salting in importance (see Table XII).

TABLE XII
PERCENTAGE OF NORWAY'S CATCH DRIED AND SALTED[a]

Year	Salted	Dried	Year	Salted	Dried
1948	19%	3%	1954	12%	5%
1949	23	4	1955	16	7
1950	15	7	1956	15	8
1951	16	7	1957	15	10
1952	16	6	1958	17	15
1953	17	9			

[a] Source: Angerman *et al.*, 1961.

Dried fish products are essential foods to the poor in many less well-developed countries, despite their minor commercial importance. Dried tuna ("moxama"), rays, dogfish, and octopus are common items in the diet of the poor in Portugal, Italy, Greece, etc. Approximately 60% of the sun-dried fish of Angola is consumed by the indigenous population (Saraiva da Costa, 1956).

In South Africa tunnel-dried hake is packed in 50-lb. lots into wooden crates and shipped to Congo (Belgian), West Africa, the Rhodesias, Mauritius, and Madagascar.

Ways and means of improving the primitive fish-drying processes generally practiced in Africa and in other tropical regions have been studied by the Fisheries Division of FAO. Sun-drying of fish is the traditional African method, but it is a process which is largely dependent on the vagaries of weather and is particularly unsatisfactory during the rainy season. In the Maldive Islands the major industry is a cured tuna (skipjack) product, called "maldive fish," largely being exported to Ceylon (3000 metric tons annually).

Test runs have been made on a processing factory on the shores of Lake Edward (East Africa). A drying tunnel equipped with fans was installed, together with an oven. Fish could be dried most effectively in 24 to 36 hours, contrasting to the 10 to 14 days needed for sun-drying during the rainy season. Smoke damages occur which need to be eliminated.

Artificial drying has been introduced in the simplified form and gives a product far superior to the sun-dried fish. It is sold on the Uganda fish market. Most of the salted-dried fish produced in Sudan and Uganda is exported to Congo (Belgian). These technical improvements will be essential to all areas of the world with less purchasing power. The limitation in tropical Africa is the lack of protective packaging, now largely leaving the fish open to insect infestation (dermestids, etc.). Sometimes larvae may account to a substantial portion of the dry matter. Although larvae contain protein, such an infestation is undesirable and requires special attention in the future.

In terms of consumed weight, dried fish accounts for 12.5% of the amount of raw fish in the urban areas of Japan and 24% in rural regions. In terms of dry matter these figures rise to 82% and 157%, respectively, of the raw fish. These data reveal several interesting relationships but chiefly indicate the importance of drying to distribution and the provision of protein to the widespread rural population.

C. SALTING

Salting is losing some of its appeal to the Western consumer, for in the postwar period salted herring, which used to be an indispensable basis for European winter provisions, especially in the rural areas, has constantly been diminishing in quantity. Salting is also becoming less important as a method of preservation (Cutting, 1961, and others), and as a whole the daily diet in the Western world has changed a great deal in the postwar period, reducing the demand for these products. The low-temperature methods and the possibilities of using frozen fish as raw material appears to have given a revival to the salting procedure and now also as a spicing device.

Salted cod for export has been primarily produced by Canada, Norway, Iceland, and Denmark, while France, Portugal, and Spain are constantly supplementing their growing domestic production. The main consuming centers for this product are to be found in southern Europe, Latin America, and parts of Africa. Large modern factories have been created in France and Spain. In recent years salted cod has experienced almost a boom, chiefly due to the greatly expanded codfish activities in the northwest Atlantic area, off Greenland and Newfoundland. The future of this product, which is only slightly susceptible to spoilage and deterioration, hinges, however, on a combination of drying and salting, making it one of the most highly concentrated protein items on the world food market (see Chapter 7).

Contributing to a reduction in the extent of salting of fish is evidently the growth of freezing operations, particularly as to groundfish. A number of quick-freezing plants have been opened for operation in recent years in Canada, the U.S.S.R., the United Kingdom, Norway, etc. Others have changed from a seasonal to a year-round operation. Owing to the need for saving space, Soviet floating factories are putting more emphasis on freezing and less on salting (see further Borgstrom, 1961b). This is most evident from the utilization figures of the Bering Sea, where more than two thirds of the catch is frozen. Only herring is salted. More than half of the catch consists of flatfishes (Anonymous, 1962d).

D. SMOKING

Fish for smoking constitutes only 2% of the world catch of food fish (see Table XIII). Smoking in the Western world has largely lost its role as a processing method and retains its standing almost entirely as a means of providing variation in the diet. This explains the decline seen in the postwar period. Nevertheless, tradition—and the desire for menu variation—give a clue to the growth of smoked fish on the Soviet and Polish scene.

TABLE XIII
QUANTITIES OF FISH UTILIZED IN COMMERCIAL SMOKING[a]

Country	1948	1957[b]	Country	1948	1957[b]
United Kingdom	137.0	75.0	Philippines	—	9.4
Soviet Union	43.4	71.4	Belgium	—	8.0
West Germany	—	25.0	Canada	10.8	7.7
United States	15.0	16.8	Norway	2.2	4.0
Netherlands	18.0	15.9	Denmark	6.8	2.6
Poland	—	11.2	Japan	2.1	1.8
Thailand	2.3	10.1			

[a] Source: Voskressenskij, 1958.
[b] Total for 1957: 700,000 metric tons, 2% of the world's catch.

The leading manufacturer is still the United Kingdom, which produces most of the "kippers," a cherished breakfast food. In the second place, however, comes the U.S.S.R., accounting for more than one-tenth of the world's total production. Smoking still plays a significant part in Western Europe. This is particularly worth noting. Besides herring, smoking is used chiefly for salmon, but the Soviet Union smokes a great number of species.

In many primitive types of society smoking still enjoys a central place. It appears likely that considerable quantities of fish are smoked which never are registered in commercial statistics. Particularly this is true in primitive societies. In Papua and New Guinea smoking permits fish to be transported and delivered within a much wider range (up to 50 miles) than otherwise would be the case. All excess fish not immediately consumed on the island of Madagascar is being smoked. Improvements in the smoking of lake fish have been attained through technical aid from FAO (Kreuzer, 1961). Along the Atlantic coast of tropical Africa two herring-like fishes, *Sardinella aurita* and *Ethmalos* sp., are smoked by the indigenous population and in effect constitute a staple item in the local diet.

In Belgium smoking is most prevalent. Some 50–60% of all fresh fish (live equivalent about 8000 tons) moving into processing is submitted to smoking. This market is dominated by various types of smoked herring, followed by sprat, mackerel, halibut, haddock, conger eel, etc. Besides this domestic production no less than 12,000 tons of salted herring are imported for subsequent smoke-curing, and, furthermore, more than 2000 tons of various kinds of smoked fish are bought from other countries (Lefevere, 1961).

South Africa has developed an export market for their smoked fish, "Cape cod fillets." They are sold to Australia, the Rhodesias, and Congo (Belgian). Surplus fish goes into this production (Dreosti, 1961).

E. SPECIALTIES

The *sugar curing* of herring and sprat is a specific kind of manufacture, mainly done in Scandinavia. Its transfer from a home art to commercial production was outlined by Borgstrom (1950). Its over-all standing among the utilization alternatives has changed little in later decades.

Fish *pickled in vinegar*, a characteristic item in Germany, Belgium, and Holland, is largely limited to herring. Some similar products are made in Scandinavia. Both raw and fried packs are available (see further Volume III, Chapter 20). These marinated products show a rise in latter years. More than 60,000 metric tons of such marinated products are presently (1961) manufactured per year. Their limited shelf life and need to be kept under refrigeration restricts the likelihood of their ever gaining major importance on a global level.

A slight *fermentation* takes place in most of these products and contributes through lactic acid formation to the keeping properties (Borgstrom, 1950, 1953; Anonymous, 1953) (see Volume III, Chapter 10). Salted, fermented fish ("fesikh" and other types) are quite popular in Arab countries (see Volume III, Chapter 20). One should also be cognizant of the central place of fermented fish sauces in southeast Asia (see Chapter 7, and Volume III, Chapter 5). From the utilization point of view these sauces also fill two additional vital functions. They allow the full utilization of excess fish in glut periods as well as offering a way of satisfying consumption independent of seasonalities in fish occurrence.

IX. Canning

Canning has held its own and slowly moved ahead in total volume. It is utilizing, in terms of landed fish, almost an identical quantity as that used in freezing.

The United States is by far the leading fish-canning nation of the world (see Table XIV). Approximately one-third of this canned fish is, however, devoted to pet food. The American packs of tuna and salmon constitute approximately one-fifth of the total world production of canned fish. Second in rank comes Japan with a pack dominated by tuna.

The Soviet Union is in third place, with a production volume approximately half that of the United States. The U.S.S.R. has developed a great number of new canned products and is presently packing a considerable number of marine and fresh-water fishes (see further Borgstrom, 1961b).

In a relative way canning has progressed strikingly in both South Africa and Australia, partly through the impetus of World War II, but these countries do not yet account for large absolute quantities. Australia's increase was not persistent, and rapidly tapered off in the 1950's to account for slightly above 10%. Most South American countries have opened fish-canning factories in the postwar period. Argentina appears to be most successful in this respect.

Among fishes which, through research, have been introduced as canned products, mention may be made of the following small-sized fish: rainbow trout (in Japan), and bangos (in the Philippines).

In the percentage of seafood canned, Morocco is the leading country (see Table XV), chiefly due to its sardine industry. Three Latin American countries come next in rank, namely: Argentina, Venezuela, and

Peru. They are closely followed by the United States and West Germany. In the latter country's statistics it is not quite clear whether or not canned food is interpreted as including more than merely heat-processed food and thus comprises also marinated and other related products packed in cans.

TABLE XIV
QUANTITIES OF FISH AND SHELLFISH UTILIZED IN CANNING (1000 METRIC TONS)

Area	Average, 1953–1955	Average, 1956–1958	1958	1959	1960	Percentage of world total, 1959–1960
World	2267	2833	2889	3300	3500	100
United States	631.7	699.3	704.4	612.8	640.5	18.5
Japan	235.0	341.7	378.0	404.3	415.6	12.1
Soviet Union	na[a]	na[a]	na[a]	310.0	340.0	9.6
West Germany	na[a]	na[a]	196.0	207.0	197.0	6.0
Spain	74.6	100.4	103.8	na[a]	na[a]	3.6
Portugal	na[a]	72.0	48.7	105.7	na[a]	49.8
France	69.9	75.6	61.5	82.6	83.7	
Canada	81.3	80.0	90.1	69.4	66.1	
Peru	na[a]	51.6	50.3	55.0	66.4	
Norway	49.1	47.9	41.3	52.5	47.3	
Venezuela	12.6	28.0	32.2	33.1	na[a]	
South Africa	61.1	32.7	na[a]	na[a]	na[a]	
Argentina	25.6	27.8	26.9	26.4	38.1	
Morocco	na[a]	na[a]	na[a]	29.8	na[a]	
Netherlands	25.0	16.9	20.0	26.6	26.8	
Chile	21.0	19.4	19.6	25.7	na[a]	
Denmark	15.9	15.7	14.6	15.2	17.9	
United Kingdom	15.4	16.5	15.3	16.2	10.2	
South Korea	6.5	8.6	8.8	10.3	8.6	
Australia	5.1	5.5	5.4	7.0	8.0	
Italy	8.2	9.0	8.9	8.2	7.6	
Belgium	1.6	na[a]	na[a]	4.0	1.5	
Greece	0.5	0.6	0.6	1.2	na[a]	
Finland	0.8	7.3	0.8	1.0	1.0	
Ireland	0.1	0.3	0.4	0.7	na[a]	
Turkey	1.5	1.7	2.4	0.5	na[a]	

[a] Figures not available.

South Africa is canning 22% of its food fish catch, but as its catches are so much lower than those of the above-mentioned countries, it does not figure in the list of the leading canning nations. These are illustrative examples of the importance of distinguishing between the utilization percentage and the size of the packs.

One of the essential characteristics of a fish for canning is that it should be abundantly available within reasonable range of the cannery. In many cases of fish which enter coastal waters for spawning the abundance is only seasonal, as with salmon on the Pacific and Arctic Coast, along the coasts of China, etc. A new feature is, however, the use of frozen raw material in the canning.

Table XV

Percentage of Aquatic Catch Utilized in Canning (1960)[a]

Area	Canned fish	
	Percentage of area's food fish	Percentage of area's total fish
Morocco	49.3	18.5
Argentina	39.8	37.8
Venezuela	39.7	39.7
Peru	35.8	1.9
United States	34.9	22.8
West Germany	32.4	26.5
Chile	25.4	9.4
South Africa[b]	21.9	11.6
France	16.1	16.1
Canada[c]	13.4	9.5
Australia	13.4	13.2
Soviet Union	13.2	11.8
Spain[d]	12.8	12.4
Netherlands	9.4	8.5
Canada	8.2	7.2
Japan	7.8	6.7
Denmark	7.6	6.7
Norway	5.9	3.0
Italy	3.6	3.6
Belgium	3.1	3.0
South Korea	2.5	2.5
Turkey	1.8	1.8
Finland	1.6	1.5
United Kingdom	0.95	0.9

[a] Calculated on the basis of FAO data.
[b] Figures for 1956.
[c] Excluding Newfoundland.
[d] Figures for 1958.

About 95% of the world's canned *salmon* pack is produced from catches obtained in the Gulf of Alaska and the Pacific. There has been a serious drop in the United States production, partly due to failure of the Alaska runs. But a corresponding increase in the Soviet and Japanese packs have managed to keep the total world figures for salmon canning on a high and rising level.

The United States has also been the largest producer of canned *tuna* as well as its principal market. Tuna canning was initiated by the United States in the first decade of the twentieth century, with the first commercial pack being produced in 1911. The annual output has expanded regularly and reached a prewar peak of 38,200 tons. The constantly mounting United States demand for canned tuna has encouraged the local fishing and canning not only domestically, on the Pacific coast, but also in other countries, producing to provide either fresh or frozen tuna as raw materials to the California canneries or to supply the final product, canned in oil.

Peru specializes in bonito; Angola and several other countries have recently become tuna packers. Ninety percent of the raw material for the California industry is captured south of the Rio Grande. The United States has recently moved into the Atlantic Ocean with its canning operations, using Puerto Rico as a base, and is in this way trying to build up a corresponding tuna empire in this area. Recently a long-term agreement was signed with Ghana permitting American tuna-catching operations in the territorial waters of that African country.

The diversity of the nature of the problems involved in the canning of *herring* and *sardines* renders it difficult to make any statements of a universal nature. Many species are involved, with some packs intended for high-priced luxury markets, and others constituting cheap staple products. Herring and sardines are canned in several regions of the world. Between the two world wars, several new producers entered the picture, resulting in a changed pattern for the international trade.

Canneries for herring, sardines, and similar species have existed for a long time in Portugal, Spain, France, Norway, the United States, and Canada. In the postwar period Yugoslavia entered the export market for canned sardines and anchovies after having started some 25 plants in the Dalmatian region. In Asia, Japan used to be the sole large producer of canned products of herring and sardines. France has one of the oldest, best established sardine-canning industries in the world. During the period 1954–1957 some 51% of the Portuguese sardine catch was utilized by the canneries (Houk, 1961). Fisheries off the South African Atlantic coast now supply fish to sardine canneries, the efforts of which have been expanding rapidly. This is also true with the French Moroccan sardine industry. Several small clupeid species have been canned in various Latin American countries, Australia, and Asia.

Both the California sardine and the sardines along the Portuguese and Spanish coasts have been subject to very drastic fluctuations and have largely disappeared in the postwar period. There is a disagreement among biologists and industry as to the real causes of this decline.

Scandinavian sardines are produced from small sprats and have developed a special market in the United States. In this country the principal producing centers are in New England. *Maine sardines,* constituted by small Atlantic herring, have, thanks to a well-conceived quality plan, managed to conquer an important place on the United States food market. In recent years canners have expressed fears for the relative abundance of Maine sardines; production has been curtailed due to a parasitic infection of the fish during part of the year. *California sardines* are Pacific sardines and closely related to the corresponding Japanese species packed as "iwashi," which unquestionably exceeds any other sardine pack in the world. *Pilchard,* the name for the adult sardine, is being packed not only in South Africa but also in England.

In lakes, fish may only be readily available when they swarm near the surface or in the shallow marginal waters at the onset of the spawning season. Such, for example, are the fresh-water vendace, canned as "ablen" in Poland. They occur as lake fish in several parts of Europe, including England, and when sufficiently numerous they allow the manufacture of a sprat-like pack. Some lake fish are too small and bony to be suitable for canning although they may be abundant, for example, the lake perch in Europe.

Under the pressure of feeding remote populations living in the permafrost region or in other nonagricultural areas, fish constitutes to the Soviet Union one of the few regionally available foods. This has meant a drive not only to develop Siberian lake and river resources, but also to preserve fresh-water fish on a large scale. A great number of different fish species are put up in cans. Examples are pike, pike-perch, bream, eels, and whitefish, canned *au naturel* or after frying (see further Borgstrom, 1961b).

X. Freezing

As regards freezing, Iceland is the leader in percentage of the total fish catch frozen, 42.4% being utilized through this method (see Table XVI). The Soviet Union ranks second among nations with 30.5%. Canada is resorting to freezing almost to the degree the Soviet Union is, but this is nearly entirely due to the extensive use of freezing in Newfoundland, where it is well nigh an exclusive raw material base for distant consumption and even reprocessing. Thirty-five percent of the Newfoundland catch is frozen, while 53% is salted or dried (cured). Only a little above one-tenth of the total catch in the United States is processed through freezing, and a fourth of this is shellfish, chiefly shrimp.

When calculated on the basis of food fish, subtracting what goes into reduction plants, these figures change (Table XVI) to a substantial degree, as, e.g., in Denmark, Morocco, Norway, United States, South Africa, Peru, and Chile. The following general picture emerges. Iceland freezes more than half its food fish (52.1%). The U.S.S.R., Canada, Denmark, and Morocco are all characterized as moving about one-third of their food fish via freezing. Australia shows a figure of one-fifth (21.1%), and the relative figure for the United States brings its utilization percentage for freezing up to 17.1%. The high Moroccan figure is chiefly explained by the delivery of frozen sardines to the French canning industry.

The earlier mentioned objections and deficiencies in statistics, however, may make quite a significant difference in the computation of these figures. It seems obvious that the tuna which is frozen at sea and later canned is not included in the United States figures. Appreciable amounts of Pacific fish is bulk-frozen for use as mink feed in the United States and Canada. Frozen fish is also employed by fur breeders in Scandinavia. Another important item with a tradition going back to the 19th century is the freezing of bait. In Denmark frozen fish is also used as feed in trout pond plants.

TABLE XVI

PERCENTAGE UTILIZATION OF FROZEN FISH AND SHELLFISH (1960)

	Frozen fish	
Area	Percentage of area's food fish	Percentage of area's total fish
Iceland	52.1	42.4
Newfoundland	38.9	35.1
Soviet Union	34.1	30.5
Canada	33.9	29.9
Canada[a]	31.1	22.0
Denmark	29.9	12.1
Morocco	29.9	11.1
Australia	21.1	20.8
Norway	19.0	9.7
United States	17.1	11.2
Finland	16.2	15.2
Japan	14.9	12.8
United Kingdom	11.8	11.2
South Africa[b]	11.5	6.1
Belgium	11.3	11.0
Peru	9.4	0.5
Portugal	7.7	7.7
Chile	8.0	2.8
West Germany	6.4	5.2
Argentina	5.1	4.8
Greece	5.0	5.0
Netherlands	4.1	3.7
Faeroe Islands	4.8	4.6
Italy	3.4	3.4
Ireland	2.1	2.0
Turkey	1.25	1.20
Pakistan	.52	0.50

[a] Excluding Newfoundland.

[b] Figures for 1956.

Furthermore it has to be borne in mind that only a minor portion of the one-third of the Soviet catch that is frozen, reaches the consumer in this form. Most of it is delivered to the fish combines bulk-frozen for subsequent defrosting and reprocessing through canning, smoking, and drying in various parts of the Soviet Union (see Borgstrom, 1961b).

More interesting, however, is the fact that when analyzed on the basis of quantities (see Table XVII), the amount of fish frozen in 1959 by the Soviet Union appears to be more than twice as large as that frozen by the United States, and when including fish alone, excluding shellfish, it is more than three times larger. As a substantial portion (approximately one-third) of the fish frozen in the United States becomes pet food and bait, the discrepancy is still larger. The amount of fish frozen in Japan also exceeds that of the United States, and is rapidly moving up to that of the Soviet Union.

TABLE XVII
QUANTITIES OF FISH AND SHELLFISH UTILIZED IN FREEZING
(1000 METRIC TONS)

Area	Average, 1953–1955	Average, 1956–1958	1958	1959	1960	Percentage of world total, 1959–1960
World	1700	2433	2696	3000	3300	100
Soviet Union	na[a]	na[a]	na[a]	825.0	na[a]	27.5
Japan	287.9	458.7	528.6	642.1	794.9	22.6
United States	274.2	328.1	271.0	385.1	312.5	11.2
Iceland	195.9	263.6	319.3	293.3	251.6	8.8
Canada	213.5	259.0	260.7	253.9	272.2	8.4
Norway	104.3	109.3	120.5	146.1	154.7	4.8
United Kingdom	62.4	99.2	110.6	109.1	120.2	3.6
Denmark	37.3	43.4	56.3	60.7	70.5	2.1
West Germany	na[a]	na[a]	33.0	33.0	39.0	89.0
Peru	13.2	14.4	18.1	26.0	18.2	
Morocco	—	—	na[a]	na[a]	18.2	
South Africa	12.8	22.0	—	—	—	
Belgium	4.8	na[a]	na[a]	18.3	16.0	
Netherlands	7.1	10.6	11.1	11.8	na[a]	
Australia	na[a]	8.1	9.6	10.8	12.6	
Finland	2.0	5.6	7.0	10.0	10.0	
Chile	0.1	4.4	6.6	7.7	na[a]	
Greece	0.9	1.5	na[a]	5.0	na[a]	
Italy	2.3	2.8	3.9	4.9	7.2	
Argentina	1.1	0.1	na[a]	2.6	4.8	
Faeroe Islands	1.0	2.2	2.8	2.2	5.0	
Turkey	2.8	7.6	4.0	1.2	na[a]	
Ireland	0.3	0.4	0.5	0.9	0.7	
Pakistan	na[a]	na[a]	0.7	0.7	1.5	
South Korea	0.1	6.6	10.4	0.5	0.3	

[a] Figures not available.

As indicated above some frozen fish moves into other channels than that of human food. Use for bait is significant both in the United States and Japan. Japanese high-seas fishing is almost entirely serviced by frozen bait of sardine, saury, and squid. Long-line fishing of tuna in all countries depends nowadays on frozen bait. Squid is considered particularly desirable and efficient. In Japan frozen sardine and saury are employed in the raising of eel. Furthermore frozen fish in Japan has become an important export article. Frozen tuna is canned in the United States and Japan, skipjack in Italy. This, together with tradition, explains why only minor quantities of frozen fish are consumed in the Japanese homeland. Sardine, herring, mackerel, saury, and squid are sold frozen or defrosted when fresh market fish of these species are short.

More than one-fourth of all fish being frozen in the world today can be attributed to the Soviet Union. The corresponding figure for the United States is 11%. These figures challenge the common and frequently made statement that the United States is the leading fish-freezing nation of the world. Before any definite conclusions can be drawn in this respect, however, this whole field needs a thorough study, making the clear distinction, suggested above, between primary and secondary utilization.

Belgium constitutes another example of the deficiencies in available statistics. It could appear that the amount of fish being processed through freezing is 2–3 times larger than the catch moving into the canning industry. This does not reflect the actual conditions, as a considerable portion of the frozen fish is being reprocessed through smoking, marinating, and canning (Lefevere, 1961). Possibly an adjustment in the statistics to take this into account explains the sudden drop in the 1960 canning figures and the increase in figures for freezing fish.

Contributing to the growth of freezing is the decline in salt processing of cod, herring, and other fish. This is particularly felt in Newfoundland and Iceland. New freezing plants have constantly been brought into operation, several on a year-round basis. This has meant a general strengthening of the market for frozen groundfish (Ronayne, 1959).

Newfoundland and Iceland are in some respects special cases, as both constitute raw material bases and freeze fish—chiefly in bulk—for delivery to the United States fish-stick industry and, in the case of Iceland, for sale to the U.S.S.R. and United Kingdom.

Nonetheless it is worth noting that, in spite of the progressive expansion of fish freezing during the postwar period, this method of processing still is on a level with canning as a major method of preservation, disposing of approximately the same amount of landed fish.

The gradual transfer of processing operations from land-based plants to the sea constitutes one very significant trend in postwar fish utilization. This development is further analyzed below. Unquestionably this trend has given particular emphasis to freezing. Freezing is even preferred to salting in sea-going operations, and is considered economically more advantageous by the Soviet experts in the field (see further Borgstrom, 1961b).

The floating freezing factories, discussed previously, obviously have had a tremendous impact on the more universal application of the freezing method and have largely dictated the utilization pattern in a great number of countries. On the other hand, it must once again be stressed that until clear distinctions are made among primary, secondary, and tertiary levels of processing, no satisfactory evaluation is possible as to the true role of freezing in modern fish utilization.

In the wake of the considerable expansion of the world's freezing capacity at sea, several interrelated developments are taking place. In the United Kingdom the airplane carriers "Queen" and "Theseus" have been converted into freezing-factory ships serving 100 trawlers at sea. Helicopters are employed to transfer the catches from trawler to carrier. Trawlers may also go alongside, and while unloading their catches they are replenished with stores, ice, and bunkers so that they can make new catches without returning to port. The carriers will each produce a minimum of 18,000 tons of frozen fish a year, along with 20,000 tons of first-quality whitefish meal (Hilton, 1960).

The new West German freezing stern trawlers stay out about 5 weeks and freeze about 60% of their catch. This fish is bulk-frozen and thawed ashore (Anonymous, 1961b). An intermediary type of operation was that tried out by the Torry Research Station in experiments with the "Northern Wave," a converted 185-ft. trawler which in Arctic waters froze approximately one-fourth of the catch, but iced the remainder. The feasibility of this procedure was well proved. Cod and haddock were the chief fishes. This procedure allows less velocity, longer fishing trips, and larger catches per day and per ton of fuel. This experimentation resulted in the stern trawler "Lord Nelson." The first part of the catch is gutted, beheaded, frozen in blocks, and stored at —20°F. The later catch is iced and sold through traditional channels. The frozen fish is defrosted dielectrically and smoked, filleted, or sold as quality fresh fish. Should operation results warrant it, the ship can be converted into a full freezer.

The freezing capacity of receiving ports have also been largely expanded. This is true of major fishing centers like Murmansk (U.S.S.R.), Grimsby (England), and Polish ports (Anonymous, 1960). In order to keep pace with this growth of the freezing fleet a major expansion is also taking place in the erection of freeze-storing facilities in most major fishing ports.

XI. Industrial Fish Utilization

A. TERMINOLOGY

No adequate terminology has been developed for describing the utilization of fish catches for other purposes than direct human consumption. The designation "fish for non-food purposes" is misleading, as the major part of the fish products ends up as human food. Most of the products falling into this category are feeding stuffs, such as fish meal, fish solubles, etc. Particularly in the United States, the jargon developed in trade journals uses the term "industrial fish" for the raw material employed in the manufacturing of these products. This also is a misnomer, as the term would comprise all fish being used in industrial manufacturing and consequently become almost synonymous with "processed fish." "Trash fish" is a term originating from those days when only fish of inferior, noncommercial species and excess lots, glutting the markets, were brought to reduction. Even this term is, in the light of modern production methods, no longer suitable. There is the need for a terminological revision in this field.

The most adequate designation for this field of industrial fish processing seems to be the "fish byproducts industry." Its manufactured products are the following:

fish meal
fish solubles
fish flour
fish silage
protein hydrolyzates
hormones (insulin adrenaline, pituitary hormones)
vitamins (A and D)
miscellaneous (cholesterols)
organic fertilizers

This industry, then, deals with the production of protein feeding stuffs and oil from the processing of offal and from fish less suitable as direct human food. Depending on whether the raw material is rich or poor in fat, the industry has developed along slightly different lines.

B. SILAGE

Fish silage is prepared chiefly in Denmark, Norway, and continental Europe. Coarsely chopped fish or offal is acidified with a mixture of hydrochloric and sulfuric acids to a pH of about 2.5. After a digestion period of a week or so, the silage is ready and remains stable for months. It must be neutralized before being added to the feed of an animal. By using formic acid, a satisfactory digestion and preservation is achieved at a pH of about 4.5, and the product does not need to be neutralized before use. A similar result can be obtained with acetic acid. For further information see Chapter 9, this volume.

C. MEAL

The largest part of the world's fish-meal production is from oil-rich species such as "anchoveta" (Peruvian anchovy), menhaden, herring, and pilchard. Very large proportions of the total catch of these species go to the reduction factories. The total United States menhaden catch, aside from the little amount used for bait, is so utilized. In contrast with the fairly regular, all-year-round supplies of whitefish offal, the supplies of oily pelagic fish, such as those mentioned, are concentrated in certain seasons, which may be very short. Moreover, even within the fishing season the supply rate is highly variable, as can be seen from the gluts and scarcities suffered by several countries.

TABLE XVIII

QUANTITIES OF FISH AND SHELLFISH UTILIZED IN REDUCTION AND MISCELLANEOUS PROCESSES (1000 METRIC TONS)

Area	Average, 1953–1955	Average, 1956–1958	1958	1959	1960	Percentage of world total, 1959–1960
World	4400	5100	5180	7200	8400	100
Peru	na[a]	na[a]	755.7	1952.3	3314.6	33.5
United States	885.0	985.0	885.0	1027.2	968.0	13.6
Japan	337.0	330.0	338	706.3	882.9	10.3
Norway	1020.0	890.0	na[a]	716.3	796.6	9.8
Denmark	162.0	318.0	422.0	479.1	345.7	4.8
Soviet Union	na[a]	na[a]	na[a]	343.0	350.0	4.1
Canada	199.0	239.0	240.1	239.2	106.8	76.1
South Africa	182.0	126.0	185.0	210.0	na[a]	
Chile	26.0	78.0	108.0	172.0	171.9	
Iceland	21.3	46.0	46.0	143.0	110.4	
Morocco	na[a]	na[a]	na[a]	na[a]	100.6	
United Kingdom	132.5	75.9	56.0	71.1	58.3	
India	54.3	72.6	70.5	54.3	97.4	
Netherlands	49.0	38.0	34.5	42.7	31.3	
Spain	4.5	12.8	23.7	23.5	23.4	
Pakistan	na[a]	na[a]	12.5	13.2	15.4	

[a] Figures not available.

In this general area of fish processing, outside of direct manufacturing of human food, the United States was the leading country up to the latter part of the 1950's, accounting for 16% of the world's total, but it is now second in rank (see Table XVIII).

Peru, within a brief period of time, skyrocketed her total catch, becoming the third-ranking nation in 1959, and surpassing the United States in 1960 with 3.5 million metric tons. More than 90% of this sizeable catch goes to reduction plants for the manufacturing of fish meal. This has brought Peru to the top position in the world in the manufacturing of this commodity, accounting for one-third of the world's catch used for this purpose.

Catch of fish alone, exclusive of shellfish, and the percentage of that catch used for reduction in 1959–1961 by 5 countries is shown in the accompanying tabulation.

	1959		1960		1961	
	Fish catch[a]	Percentage to reduction	Fish catch[a]	Percentage to reduction	Fish catch[a]	Percentage to reduction
China (estimated)	5.0	na[b]	5.8	na[b]	6.5	na[b]
Japan	4.32	12	4.52	14.3	5.5	17
Peru	2.15	85	3.53	94.7	3.8	94
Soviet Union	2.71	12	2.98	15	3.36	15
United States	2.03	56	1.96	49	1.23	52

[a] In million metric tons. [b] Not available.

Peru has maintained its high-ranking position and strengthened still further both its relative and its absolute standing since 1960. The fish meal production exceeded half a million tons in 1961, corresponding to a catch of more than 3 million metric tons. The first Peruvian reduction plant was put in operation in 1950. In 1961, 3.8 million metric tons of fish were channeled into reduction, almost 3.5 times the United States menhaden catch, for decades the world's largest single fishery. These "anchovetas" are processed into 570,000 tons of fish meal and 36,000 tons of fish oil, most of which is exported.

For a great number of years second place, next to the United States, was held by Norway. The Peruvian competition, coupled with poor winter herring catches, has reduced their manufacture by one-fifth. In the meantime, Japan increased its fish meal production 2–3 times during the 1950's, and thereby moved into the position of being the third nation as to fish reduction. This is partly explained by its high degree of waste utilization and its mounting absolute catches, but still more it is due to the present drive to build up within its islands an animal production. Its own agriculture cannot provide the protein required for such an endeavor. This explains why large, newly built, processing factory ships are being sent by Japan into the Bering Sea and other waters for large-scale production of fish meal (see also Tables XVIII and XIX).

Denmark's production of fish meal and fish silage has also been growing in a spectacular way (tripled in the 1950's) and in 1959 accounted for close to three-fourths of its total catch. A marked dip, how-

TABLE XIX
PRODUCTION OF FISH MEAL AND SOLUBLES (1000 METRIC TONS)

Area	1958	1959	1960	1961	Percentage of world total (1961)	Cumulative sum (%), Σ
World	1430	1900	2100	2300	100	
Peru	126.9	332.4	569.0	600.0	26.0	
United States	343.2	428.1	358.3	360.0	15.6	41.6
Japan	215.3	256.8	281.7	320.0	13.9	55.5
South and southwest Africa	100.1	136.8	152.3	170.0	7.4	62.9
Norway	117.9	133.9	156.0	160.0	7.0	69.9
West Germany	76.6	91.6	82.5	90.0	3.9	73.8
United Kingdom	78.2	79.2	76.2	75.0	3.2	77.0
Canada	65.6	70.4	36.4	70.0	3.0	80.0
Soviet Union	43.9	62.8	63.0	70.0	3.0	83.0
Angola	42.8	46.2	50.0	60.0	2.6	88.2
Spain	12.4	11.0	98.7	60.0	2.6	85.6
Denmark	65.6	70.8	50.0	55.0	2.4	90.6

ever, is noticeable in 1960 in its domestic production of fish meal, as well as in the United States, Canada, Iceland, West Germany, and the Netherlands (see Table XIX). This is generally interpreted as due to the impact of the large quantities of Peruvian meal becoming available rather suddenly without time for a normal adjustment of the markets.

Fishing for reduction purposes is in general not permitted in the Soviet Union. Fish meal, whether manufactured on shore or on board the numerous factory ships, is chiefly made from wastes after beheading, evisceration, and filleting. One exception seems to be the Alaska pollock ("muntja"); for its reduction special license is given (Borgstrom, 1961a).

In the wake of the Peruvian gains, neighboring Chile has also moved into the fish meal market. No less than 63% of its Pacific catch goes into such feeding material. This figure presumably will be still higher in the future. Plans have just been announced for a large joint enterprise involving the United States, South Africa, and Chile to start operations in a modern 50-ton-per-hour reduction plant in the northern Chilean city of Iquique. It will be in continuous operation and have an annual capacity of 360,000 metric tons of raw fish or 72,000 tons of finished meal. It is worth noting that the fish meal and oil production in adjacent Ecuador is entirely geared towards providing the margarine industry with fat. The resulting meal is consumed domestically. Cannery wastes are also converted into meal.

Close to half the catches of Norway and South Africa is utilized for reduction. A still higher figure pertains for southwest Africa. About two-fifths of the large catch of the United States is processed into meals and solubles. For other countries see Table XX.

In most countries the utilization percentage for reduction purposes shows a large fluctuation. This is due to the fact that this item constitutes a buffer. The amount that commercially can be channeled into human food cannot be drastically increased.

Countries like Norway and Iceland are good examples of this phenomenon. The quantity of herring frozen and salted is fairly stable from year to year, since it is limited by the capacity of the markets. A great increase in the herring catch has therefore invariably caused increased quantities being taken to the reduction plants, for the production of meal and oil. This happened in Iceland in 1959, when the quantity reduced was more than three times greater than that of the previous year (see Table XVIII).

A more efficient utilization of waste, offal, and stickwater is conducive to a sound fish economy. The most important new trend in this field is the greater emphasis being put on saving fish protein. The stickwater, generally not utilized in Europe, constitutes an important wasted protein source. Large quantities of protein could be saved from returning to the sea.

In the United States the processing of fish stickwater to provide condensed fish solubles makes a major contribution to the profit of the fish meal and oil industry. Millions of pounds of such solubles are used by the animal feed industry to enrich nutritious food concentrates, and the demand is expanding. Similar relationships apply to the solubles industry in South and Southwest Africa. Whale solubles represent a new profitable feature and a valuable additional source of animal protein for feeding purposes.

TABLE XX

PERCENTAGE OF FISH AND SHELLFISH UTILIZED IN REDUCTION AND MISCELLANEOUS PROCESSES (1960)

Area	Percentage of total catch	Area	Percentage of total catch
Peru	94.7	Soviet Union	10.9
Denmark	59.5	Newfoundland	9.7
Chile	63.0	India	8.4
Morocco	62.4	Finland	6.1
Norway	48.9	United Kingdom	5.4
South Africa[a]	47.0	Argentina	5.0
United States	34.6	Pakistan	5.1
Canada[b]	29.2	Belgium	3.0
West Germany	18.3	Spain[c]	2.8
Iceland	18.6	Ireland	2.3
Canada	11.7	Turkey	1.6
Colombia	11.8	Australia	1.3
Netherlands	9.9	South Korea	1.0
Japan	14.3		

[a] Figures for 1956.
[b] Excluding Newfoundland.
[c] Figures for 1958.

Greater interest is also shown in fishery byproducts by pharmaceutical and manufacturing firms for developing new articles or for use as cheaper and better raw material. For example, the eyes of codfish contain a high amount of vitamins. Various hormones can be manufactured from the entrails, etc.; more liver is therefore saved aboard for this purpose. Still an enormous wastage of potentially valuable material occurs in many fishing and processing operations. It is estimated that more than 50,000 metric tons of waste are discarded annually by salmon canneries in Alaska. In the Soviet Union, cod livers are converted into various types of human foods as pastes, cakes, etc. This is an important upgrading, allowing the valuable protein of the livers to be used, besides fats and vitamins. Some Soviet factory trawlers operating in the North Atlantic have special processing lines installed for this canning of cod livers.

In Hungary low-grade fresh-water fish, otherwise poorly utilized for human consumption, is alkali-treated and the protein extracted (Lörincz, 1951). This protein is used as a filler for canned meat and sausages.

Most of the fish meal is used in the raising of poultry and hogs. Minor supplementation to cattle feed is advantageous too, and conducive to better milk yields (Breirem *et al.*, 1961). Fish meal is also employed in the raising of fur animals (mink, silver fox, etc.), and as feed in hatcheries and trout-raising ponds.

D. FLOUR

Great attention has been devoted to fish flour, i.e., fish meal suitable for human consumption. This whole matter is discussed at great length in Chapter 7. So far fish flour has chiefly been manufactured on a purely experimental scale and in pilot plants. It has largely been used clinically and in trial marketing.

XII. Herring, Sardine, and Pilchard

Even if the over-all trends have the character of rather an evolutionary development, changes have been almost revolutionary as to the utilization patterns for specific species or in particular countries. This is not least evident with herring, as the trend in Norway indicates. In twenty years the fresh sector has, on a percentage basis, dropped from 20% to less than one-tenth. Freezing, in the short lapse of ten years, has developed from insignificant amounts to 53,254 tons or 8% of the total herring catch. Despite a general declining trend for salting, this pack has nearly doubled. Canning showed only minor changes. The rebuilding of the European animal production made the Norwegian meal production double its output—though in recent years it has decreased somewhat, faced with the Peruvian competition.

The herring has somewhat misleadingly been called the pig of the seas, providing first-class "pork"—a fat-rich type of meat. As to nutritive value, herring flesh compares well with pork, and so the designation is reasonably valid. But it is a sad commentary on world economy and the planning of mankind that more than half of this highly rated oceanic nutrient, constituting such a perfect human food, moves into livestock and poultry feeding, and only after a wasteful conversion reaches the tables of the world's extravagant nations. In Denmark 70–75% of the herring catch goes to meal and oil factories.

In 1960 the world catch of herring, sardines, and related fishes amounted to 3.5 million metric tons. The Atlantic herring contributed 76%, Pacific herring 16%, and the Baltic herring 8%. The Pacific herring catch (in metric tons) is as follows:

Soviet Union	258,830	United States	53,680
Canada	221,540	Japan	18,590

The 1959 North American herring catch of 414,500 tons was three times as great as the catch of any other food fish landed at North American ports. Other catches were: salmon, 153,340 tons; tuna, 146,300 tons; groundfish, 68,668 tons; halibut, 35,800 tons; and sardines, 35,364 tons. In value, however, herring ranked fourth at 9 million dollars, compared to 101 million dollars for tuna and 13.5 million dollars for halibut.

In British Columbia the catch of Pacific herring ranks first in landed weight and second to salmon in landed value. While the herring catch in recent years has averaged about 3 times the weight of the salmon catch, it has only been about one-fourth as valuable.

Herring have been fished in British Columbia waters since 1877, when a catch of about 75 tons was made. In 1955–1956 there was a record catch of a quarter of a million metric tons. The general trend has been toward a steady expansion of this fishery, primarily in response to market conditions. The most important influences were the development, between 1904 and 1927, of an Oriental market for dry-salted herring. This was lost between 1927 and 1934, when the reduction fishery for oil and meal was started.

The expansion of the Canadian herring fishery from 1904 onward was accomplished first through the increased exploitation of southern British Columbia stocks, followed in the late 1920's and 1930's by the expansion of the fishery northward, and finally, since the end of the World War II, by a still further increase and a heavy exploitation of almost all stocks.

The California packers lost much of their market when the sardine shoals virtually disappeared in 1947–1948. When these returned, in 1956, California's catch was in sharp competition with cheaper Japanese and South African exports. In 1958 the California industry packed 2.13 million cases of fish in oval cans with tomato sauce but were largely priced out of the international market. A pack of 2 million cases of Maine sardines was also made in that year.

The sardine fishery is the mainstay of Morocco's fishing industry, accounting for more than 80% of all fish landed. Most of this fish is utilized through canning (Kreuzer, 1961). Some part of the catch is frozen and delivered to France for subsequent canning.

Soviet fleets have been catching large quantities of African sardines

(*Sardinella aurita*) off the coast of West Africa ever since 1958 (see further Borgstrom, 1961b). Much of this fishing is done by pumping directly on board with hoses, where the fish are immediately chilled to reduce slime formation and then taken directly to the freezers. The bulk frozen product is subsequently transported to either Cherzon on the Black Sea or Kaliningrad on the Baltic, for canning or smoking.

The world's largest pilchard (*Sardinops ocellata*) catch is that brought into the southwest coast of Africa: in 1961, 378,072 short tons to Walvis Bay in southwest Africa and 443,499 tons to the Cape coast of South Africa. Most of this fish goes to canneries. Only the offal is presently sent to fish meal plants. The large canneries pack around one million cans, that is, 300 tons of fish into 18,000 cans per day or 1000 cans per hour.

XIII. Redfish

As related in Chapter 7, and in Volume 1, Chapter 2, ocean perch has in the postwar period become an economically important fish and figures largely in Atlantic catches on both sides of this ocean. The Soviet trawlers operating in the North Atlantic all report redfish as their dominant catch (in 1958 even 94% of the total). Almost all redfish caught by West European countries goes to freezing, generally after filleting. The Soviet catch is bulk-frozen.

XIV. Sand Eels

Herring, menhaden, and Peruvian anchovy ("anchoveta") are no longer the only source for manufacture of fish meal. In many places an indiscriminate catching of trash fish takes almost anything. Furthermore, in the postwar years the exploitation of certain new species appearing in large numbers has started. Most of these fish constitute food to other fish important as human food. Consequently the long-range effect of this trend remains to be established.

Important among these new sources of fish for byproduct production are the sand eels—now landed in large quantities by countries like Denmark (78,000 tons in 1960) and West Germany.

XV. Tuna

Tuna operations have largely expanded not only in the two traditional countries but in a number of other fishing nations, now entering this field on a large scale (U.S.S.R., Italy, Spain, Greece, South Africa, etc.). The world tuna catch has risen from about 1.5 million metric tons in 1955 to more than 2 million tons in 1961.

The large-scale conversion of the clipper into seiners, which took place in the United States in recent years, is another important trend (see further Borgstrom, 1963c). The catching units have constantly become larger. The United States' "Nautilus" is a converted mine dragger with a capacity of 850 tons of tuna. Having refrigerated mother ships accompany the minor fishing vessels is still another way of improving the care of the tuna on board as well as increasing capacity. The use of refrigerated fish carriers regularly collecting catches from several fishermen is being tried in warm waters. Such carriers operate in the Persian Gulf along a 150-mile stretch of coast in the vicinity of Abadan.

The United States is taking 90% of its raw material sent to the California industry from the Pacific waters of tropical South and Central America. But for a growing population these catches no longer suffice, and operations have been initiated in the tropical Atlantic. United States tuna ships have moved into these waters. A new processing base has been developed in the island of Puerto Rico, with three major canneries; besides delivery from American ships, large Japanese liners bring in at least one-third of their tuna catch from equatorial Atlantic waters. French tuna ships land frozen tuna in Dakar, and from there they are brought by special carriers to the United States plants in Puerto Rico. Special arrangements have further been made by the United States for catching in the coastal waters of Ghana.

In 1958, 2.5% of the Japanese tuna catch was delivered to mother ships—in total, 10,710 metric tons. The Japanese are investing in larger vessels with a freezing capacity of 8 metric tons per day as against 3 tons at present. On the island of Si Amil, North Borneo, a Japanese company has erected a base for its South Pacific operations and started a processing plant. A second such Japanese tuna base is being created in the Fiji Islands. Japanese tuna canneries are also being erected in the Caribbean, in Trinidad and the Dominican Republic. In a similar way tuna bases are being created in Ghana and Liberia, with modern refrigerated warehouses for temporary holding of the Japanese Atlantic catches. Japanese long-liners also fish regularly in both the eastern and western sections of the tropical Atlantic.

Most significant are the Soviet aspirations as to tuna. A number of specialized tuna boats are on order in Japanese as well as Soviet shipyards (see further Borgstrom, 1961a). A new 930-ton tuna vessel with a cruising range of 60 days, built at a Leningrad shipyard, will be assigned to the Soviet Far Eastern fisheries for the development of new tuna fisheries in the Pacific and Indian Oceans.

South Africa started catching tuna a few years ago, but is selling most of its catch in a semi-prepared frozen stage for subsequent canning. In this respect they are following Japanese practice in their deliveries to United States factories. This is another case where secondary utilization of the catch unquestionably has a major effect on available statistics, as a clear distinction is not made in this respect.

The Canadians are also entering into tuna operations. New ships are being built on the Pacific coast for service in this ocean in competition with the United States. They will have a fish-carrying capacity of 730 tons (World Fishing, 1962). Freezing of the fish will be undertaken in jacketed holds. These vessels will have a cruising radius of 15,000 miles and be completely self-sufficient for periods exceeding three months. They are planning to fish off the North Island of New Zealand, where the average tuna weighs 75 lb. and the largest may weigh up to 200 lb., compared to a 26-lb. average for the Canadian west coast. Two carrier vessels will bring the seiners' catches back to canneries in British Columbia (Anonymous, 1962a).

Taiwan is starting tuna fishing off the northern coast of the island of Madagascar, reportedly backed by American interests, for sale of tuna to the United States. Large liners are being built to their order by Japanese shipyards. Japan is studying a similar project in cooperation with canneries to be built on the southern coast of Madagascar.

Egypt has on order several modern tuna vessels and is planning to join in the fishing of the Middle Atlantic (see *Fishing News*, Jan. 19, 1962).

All these expansions will contribute to a strong reinforcement of world canning operations, as most of this tuna, even that caught in distant waters, in the final run ends up as canned tuna. A minor portion may go into sausages of various types (see Section XX below). A special industry is the cured skipjack, manufactured in the Maldive Islands (see Section VIII, c).

Spain, the fourth nation as to the size of its tuna catch, utilizes most of it in canning. The liver oil of tuna is important also as a vitamin source, particularly in Spain (Lopez-Capont, 1961). Spanish tuna-hunting starts off the coast of Morocco and then along the African coast from Agadir to the Bay of Guinea. Their floating freezing vessel "Saupita" stops in port at Casablanca, Dakar, and other places. Its production is taken by refrigerated carriers back to Spain (Gomez-Salome, 1960).

Italy is no longer satisfied with its tuna catches in the Mediterranean and is now supplying their carriers with tuna from the same general region off the coast of tropical Africa as that being fished by Spain.

XVI. Shark

One important new trend in fish utilization is the effort to include shark among the useful fishes. During the war years shark was taken in large quantities beyond the Pacific coast of North America, near Ireland, and in South African and Australian waters. Many tropical waters abound in various elasmobranch species. They are also encountered not infrequently in cooler regions. Norway catches increasing quantities, chiefly off the Shetlands (32,810 tons in 1961). Waters particularly shark-infested are those of the Caribbean and the Bay of Bengal.

As clarified in Volume I, Chapter 6, the flesh of elasmobranchs is heavily laden with urea. This has to be removed to make it, from the point of view of taste, acceptable as a direct human food. This has been done in a satisfactory way, rendering good dried and canned products (Bose *et al.*, 1958). An odorless fish flour has also been manufactured in India (Pillai, 1957) by submitting the flesh to a primary fermentation. Mexico has installed modern shark-freezing plants.

Shark flesh has also been successfully converted into meal for use as a livestock fed. In this case the urea need not be removed.

Shark is Australia's third most important fish in terms of quantity and is principally sold through "fish and chips" shops. This means its catches enter into the fresh market category. Size and season restrictions have been introduced to protect the stock.

Several million pounds of shark flesh are nevertheless discarded each year (in South Africa, the Caribbean, Pakistan, etc.). Only the liver is utilized, and possibly the skin. This is a loss to the global household, particularly as often the sharks abound in waters off countries short of protein.

XVII. Crustaceans

A. GENERAL

King crab and shrimp are the major crustacean catches. The United States has the largest catch of crustaceans in the world. Approximately half goes to the fresh market; one-third is frozen, chiefly shrimp. Less than a fifth is canned, mainly king crab. Japan holds second place. In that country the fresh market takes one-third. Drying and canning account for one-third each. King crab dominates the canned pack. It must, however, be noted that the size of the Chinese catch of crustaceans is not known and could supersede that of both the United States and Japan.

B. KING CRAB

King crab is predominantly processed through canning. The United States pioneered this venture back in the 1930's. The Soviet Union now appears to be the largest catcher, closely followed by Japan (see Table XXI). The latter nations early moved their canning operations out to sea. Most of the "Chatka" crab consists of king crab, in the U.S.S.R. generally designated as Kamtchatka crab; it is being processed on floating canneries (see Section VI). It is reported that the U.S.S.R. recently added a third large factory ship to its crab-fishing fleet in the North Pacific.

If the Dungeness crab is included in the United States catch, the gap between Japan and the United States narrows down to almost nothing. The Dungeness crab is utilized basically in the same way as the king crab, that is through freezing and canning. Minor quantities are sold unprocessed.

In the spring of 1962 two floating king crab canneries and one freezing vessel belonging to Japan were operating in the Bristol Bay area. A pack of 130,000 cases was anticipated. The freezing vessel is to manufacture 300 metric tons of frozen product. In the fall of 1961 three 1500-ton refrigeration motherships froze king crab meat in areas close to Bristol Bay. This pack was mostly sold frozen to Europe for subsequent canning, another example of different channels for the primary and secondary utilization levels. One Japanese factory ship for crab canning operated in the Bering Sea, and no less than four in the Sea of Okhotsk (Pacific Fisherman, 1962b).

C. ROCK LOBSTER

The South African rock lobster (*Jasus lalandii*) and the Australian spring lobster (*Panulirus longpipes*) are almost entirely preserved through freezing, and most of the product is exported to the United States. Australia has been compelled to introduce catching restrictions, as the yearly toll from presently known grounds reaches the limit for a sustainable yield. Islands west of the Great Australian Bight are now being surveyed for possible new sources.

D. SHRIMP

Traditionally, shrimp was dried in the Asian region and constituted an essential reserve protein for the off season. In the Western world freezing has in recent years become the chief utilization channel, when the shrimp is not marketed fresh. Approximately 54% of the domestic catch in the United States is frozen, 22% canned, 20% sold fresh (gener-

TABLE XXI

CATCHES OF KING CRAB (1000 METRIC TONS)[a]

Area	1953	1954	1955	1956	1957	1958	1959	1960
Soviet Union	28.4	27.0	37.4	36.1	29.8	30.9	32.2	36.7
Japan	8.3	9.8	21.6	28.4	25.9	28.2	27.5	25.4
United States	2.1	4.0	3.7	4.0	5.9	5.1	8.5	13.0
South Korea	0.6	1.0	1.7	0.8	1.2	1.5	1.4	—
United Kingdom (Dungeness)	12.1	12.9	11.1	15.5	19.4	19.1	16.8	15.1

[a] Source: FAO Fisheries Yearbook.

TABLE XXII
CATCHES OF SHRIMP[a] (1000 METRIC TONS)

Area	1953	1954	1955	1956	1957	1958	1959	1960
United States	118	122	110.8	101.7	92.4	96.9	109.0	112.8
Japan	43.8	52.3	46.0	47.9	46.7	53.6	50.8	57.3
Mexico	na[b]	35.4	43.2	44.8	43.7	50.2	60.3	na[b]
West Germany	41.0	33.0	43.0	33.5	34.9	28.4	25.8	24.2
Brazil	na[b]	na[b]	na[b]	na[b]	na[b]	na[b]	17.0	na[b]
Netherlands	16.9	14.8	19.4	16.4	11.6	10.9	13.1	12.7
South Korea	19.9	13.8	15.3	17.6	20.4	16.3	17.6	9.4
Panama	0.6	1.7	2.0	3.0	4.2	4.6	5.6	5.5
Ecuador	na[b]	na[b]	1.7	2.3	2.1	2.7	2.8	2.8

[a] Source: FAO Fisheries Yearbook (p. 71).

[b] Figures not available.

ally iced), and 4% dried. Most imported shrimp is frozen, except minor quantities imported canned from northern Europe and some dried from Hong Kong and Japan. A major portion of shrimp caught in the Caribbean and Latin America is delivered to the United States market, some already packed for retailing. Mexico provides half of the United States supply. The United States is the leading shrimp-consuming nation and constitutes the world's largest purchasing market for shrimp. Chile has recently entered this market with shrimp caught in the Humboldt Stream and frozen primarily for the United States market.

There has always been an essential difference between the utilization methods developed in Europe and those of the United States with regard to shrimp. For centuries in Scandinavian waters and in the North Sea the shrimp have been immediately boiled on board, thus prolonging their shelf life. In the Caribbean shrimp was submitted to no preservation until the ships reached harbor; this practice was detrimental to quality, and in recent years icing has been introduced as well as preliminary bulk freezing on mother ships (see further Volume I, Chapter 15).

Japan is the second nation as to shrimp catch (see Table XXII). It has in recent years also extended its shrimp operations into the Bering Sea. The shrimping fleets are generally served by canning ships, but are also equipped for freezing on a minor scale (see Section VI, above). In available FAO statistics the term "shrimp" comprises a great number of different species in various parts of the world. As to the Japanese catch figures, they may have a slightly broader connotation than those of other nations.

Only 15–20% of the West German catch is utilized as human food, the major portion being converted to meal in reduction plants.

E. CENTOLLA

A significant new feature is the creation of a centolla industry in southern Chile. This is a crab from the subarctic waters resembling the king crab. Three processing plants dedicated to the utilization of this commodity are operating in the ports of Porvenir and Rosario. Most of the catch is canned and sold to the United Kingdom and other European countries.

XVIII. Cephalopods

The most important method of preserving squid is sun-drying, and it is processed in this way in the Orient, as well as in California for shipment to the East. The squids are split open, and after scraping they are spread flat on the ground and dried. They are turned frequently,

TABLE XXIII

CATCH OF CEPHALOPODS[a] (1000 METRIC TONS)

Area	1948	1953	1954	1955	1956	1957	1958	1959	1960
Japan	323.0	510.7	487.2	482.0	350.7	470.5	461.2	589.2	599.5
South Korea	9.2	19.8	10.1	19.5	23.5	41.3	35.7	49.4	43.4
Spain	na[b]	10.7	9.1	10.8	12.0	15.7	18.5	20.7	24.5
Italy	8.5	12.1	13.6	14.4	15.4	15.3	12	19.2	16.3
Taiwan	na[b]	2.8	1.8	3.7	4.3	5.1	5.4	8.1	6.8
United States	10.8	6.6	8.4	7.1	10.2	8.3	5.4	10.6	1.2

[a] Squid, cuttlefish, octopus, etc. Source: FAO Fisheries Yearbook.

[b] Figures not available.

and when thoroughly dry are packed by hand in barrels and boxes and shipped to market.

According to available statistics Japan is overwhelmingly leading as to cephalopod catch—presumably more than all other countries together (see Table XXIII). Reservation must be made for China, known to catch considerable amounts both of cuttlefish and squid.

The large Japanese catch of squids is partly canned, the dried mantle is eaten as such, oil is extracted from the viscera, and the waste is used as a protein supplement in chicken feed. Several Japanese laboratories work on the further utilization of the squid (Tanikawa and Akiba, 1952). Among other uses, it has been found to produce a good adhesive for wood.

The squids are also frozen for storage and used as tuna bait. The canning of squids, begun in California in 1920, has increased considerably since then, but stagnated in the postwar period after major export for relief through UNRRA when the war ended.

XIX. Whale Utilization

A. GENERAL

The trend toward a better utilization of the whale meat, but also toward its greater use as human food, is most evident. A large percentage of whale meat was formerly discarded, and what was saved chiefly went into animal food (see Volume III, Chapter 23). This is gradually changing. Chiefly due to Japanese efforts, the amount of whale meat saved has almost doubled in five years (see Table XXIV). To what degree this meat is used as human food is not revealed, but it is assumed that a large percentage is disposed for human purposes.

TABLE XXIV
QUANTITIES OF WHALE MEAT
(1000 METRIC TONS)

Area	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60
World	79.4	89.2	115.6	130.3	128.6	142.2
Japan	64.6	75.8	97.4	112.2	108.9	119.6
United Kingdom	5.8	3.0	5.1	4.9	4.0	6.2
United States	—	0.6	1.0	4.7	3.5	4.2
Soviet Union	1.7	2.8	4.0	1.8	0.5	3.7
Norway	2.1	1.5	1.7	1.6	3.2	3.6

The Soviet Union has built several new floating whaling factories in recent years of considerable size (44,000 register tons): the "Sovjetskaya Ukraina," "Sovjetskaya Rossija," and "Yury Dolgorvky." Several smaller ships have been lauched too, but some of these are still quite sizeable, such as the "Sevastopol" (see Section VI,B) or the "Vladivostok." The latter is a factory ship of 17,000 gross tons and was commissioned for service in 1961. It can serve as a whaling mother ship and fish cannery, can manufacture frozen fish, fish liver paste, and vitamin-rich oils, and can be utilized for whaling or deep-sea fishing. A second such ship was to be delivered in 1962. The vessel has a speed of 14 knots and is manned by a crew of 408 men. The support for its smokestack serves as a hangar for a helicopter with the special task of guiding the fishing operations. The Japanese were the first to develop a factory ship capable of performing such dual functions.

The home base for "Sovjetskaya Ukraina" is Odessa, but "Sovjetskaya Rossija" will be based in Vladivostok in the Far East. After whale hunting in the Antarctic it goes to southeast of Okhotsk for the hunting of sperm whales. Thus, this factory will be in full operation during the whole year.

The rapid and sizeable expansion of Soviet whaling becomes most evident in the growth of their Antarctic fleet (see accompanying tabulation; Anonymous, 1962c).

Season	Catchers	Floating factories
1959/60	37	2
1960/61	52	3
1961/62	67	4

The Soviet catch in the 1960-1961 season was reported as 8525 whales. These were processed into 54,000 metric tons of whale oil, 15,000 tons of whale flour, and 18,000 tons of whale liver. Meat was frozen but the amount was not disclosed.

Whale meal is also utilized as fodder (Breirem, 1940) (see further Chapter 9).

In Japan nutrients are procured from the brains of whales. Dried ether extracts are fermented with certain aspergilli after adding wheat or rice bran. More than half of the whale brain is decomposed into water-soluble amino acids and polypeptides. Insoluble material is removed by filtration, and the filtrate is vacuum-dried (Kataoka and Narita, 1959).

Japanese experts are teaching British Columbia whalers how to prepare whale meat for human consumption with the aim of laying the foundation for the export of such frozen meat to Japan (Western Fisheries, 1962b).

An important recent addition to Antarctic whaling is that at Durban, South Africa, where each year more than 2000 whales are captured.

The persistently good yields of this section are ascribed to its air reconnaissance service. Two planes are on constant patrol in these waters to locate the whales.

B. WHALE OIL

Another very important commodity which South Africa supplies in substantial quantity is whale oil. South Africa has factory ships operating in the Antarctic whaling season. Whaling is also conducted from a land station at Durban, and on a limited scale along the west coast. The bulk of the oil is exported to the United Kingdom (see Table XXV).

TABLE XXV
QUANTITIES OF WHALE OIL
(1000 METRIC TONS)

Area	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60
Norway	125.1	123.1	154.6	125.1	126.4	105.8
Japan	66	71.7	84.8	100.4	108.4	105.7
Soviet Union	29.3	27.2	25.1	36.4	37.2	60.1
United Kingdom	70.5	69.5	60.2	63.8	43.2	45.2

In spite of changed uses and a greater assortment of high-quality oils, sperm oil maintains its place on the world market. Production even increased about one half in the 1950's, with appreciable gains for the Soviet Union and the Netherlands, but a decline for Norway (see Table XXVI).

TABLE XXVI
QUANTITIES OF SPERM OIL
(1000 METRIC TONS)

Area	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60
Japan	21.3	30.6	32.2	29.5	39.6	33.0
Soviet Union	13.9	15.0	15.6	22.5	22.2	28.2
Netherlands	9.9	14.5	14.9	17.9	19.2	24.0
Norway	24.2	23.0	17.3	21.4	15.3	11.8

XX. Special Fish Products

Various special products have in different parts of the world played a significant part in an efficient utilization of available fish resources. Leading in this respect is Japan, with a rich assortment of pastes, sausages, and related products (see Arimoto, Chapter 8 of this volume).

Some of these products have a long historical tradition. "Kamaboko" is mentioned in Japanese documents of 400 years ago. But only for a century did an assortment of "kamaboko" products appear on the scene. At that time it was solely a home industry, not mechanized, and at best filling the demand of the neighborhood. The fish used for this manufacturing was not limited to one or two kinds; any fish available and suitable was used for the making of "kamaboko."

As the demand grew this piecemeal manufacturing developed into large-scale industries. As a consequence the raw material had to be sought from afar. For persistent high quality, frozen fish has now entered the scene as a raw material. About two or three years ago, blufin tuna, marlins, and whales, which used to be considered unsuitable material for "kamaboko," came to be used for this purpose. At the same time fish sausages imitating various traditional types made from the meat of terrestrial animals were introduced. This created in the 1950's a flourishing new industry. In 1960 as much as 72,000 metric tons of such fish sausages were produced (Okado, 1961).

Several pastes and sausages are highly perishable and have to be kept refrigerated. More dry types of sausages, however, are presently being tried with satisfactory results. They may keep for one month even at 30°C.

In several countries fish paste offers an excellent outlet for excess fish of varying species. Morocco has developed a special type for export to Arab countries. In Australia fish paste constitutes one seventh of the canned fish pack (FAO 1960).

Tuna meat has been made into various types of sausages, frankfurters, bolognas, etc., in the United States. On both the east and west coasts these meatless sausages have entered the food market, but have not yet become really significant (Aikawa, 1961).

Fish and chips is an outstanding and characteristic feature of the British scene, with a lengthy history. Numerous frying outlets partly explains the persistence of this item, now also available as a frozen product.

Another category of specialties with a long tradition are the sauces (see Volume III, Chapter 9).

A ready-made fish dish which was one of the earliest subject to industrial manufacturing is Scandinavian fish balls, cooked in fish bouillon. This item, along with soups, was one of the first significant ready-made foods on the commercial scene. A variation of this product are the fish cakes and fish puddings available in the United States and Scandinavian food market. The United States has a large array of fish dishes such as soups, tuna pies, etc., which unquestionably have meant much in keeping fish in the American family diet (see further Borgstrom, 1961b).

Soviet fish combines turn out large quantities of cooked and fried fish, packed in plastic bags. Continuous processing lines operate on a 24-hr. schedule to meet demands for such ready-to-eat cooked food.

The manufacture of fish sticks, breaded and fried, is a convenience item introduced on the United States market. This manufacture has lent itself well to complete mechanization. Such processing lines have been installed in Scandinavia, the United Kingdom, and the Soviet Union.

XXI. Fish Oils

A. Body Oils

As indicated in Chapter 7 fish oils have been devoted to human consumption to a growing degree. Originally they were utilized by various manufacturing chemical industries. In this respect essential changes have taken place in the utilization pattern, and this new trend presumably will persist, as such oils constitute a cheap source of fat capable of competing with vegetable oils and fats. This has been accomplished by their refinement and conversion into raw materials, essential to the oleomargarine industry. Furthermore, fish oils have the attractive characteristic of a high percentage of unsaturated fatty acids (see Volume I, Chapters 7 and 8). Menhaden oil from the United States figures conspicuously in the importing lists of West German and Dutch plants. Table XXVII gives figures calculated by the author showing the significance of aquatic oils, including whale oil, to the fat intake per capita of population in selected importing countries.

TABLE XXVII
IMPORTS OF AQUATIC OILS AND FATS (AVERAGE 1958–1959)

Area	Kg. per capita	Area	Kg. per capita
Netherlands	5.4	Belgium	2.0
Sweden	4.2	France	0.46
Denmark	3.3	United States	0.19
West Germany	2.7	Soviet Union	0.15
United Kingdom	2.6		

West Germany has, in addition, driven ahead with the erection of a fish oil processing industry of their own, using herring as the chief raw material source (Hass, 1961). Fish meal constitutes an attractive byproduct.

Studies are presently being conducted in the United States with the aim of developing alternative uses of fish oils, particularly menhaden oil, in anticipation of the possibility that vegetable oils may become more attractive than menhaden oils for use in oleomargarine. The stability of fish oils needs to be improved. Fish oil constituents may be employed in ore flotation. Other possible new applications include the use of fish oils in fungicides, insecticides, pharmaceuticals for coronary disease, and heat-resistant paints (Lopp, 1959). Table XXVIII shows fish body oil production in 7 countries.

B. Liver Oils

Fish liver oils have been extracted on board ordinary trawlers for several decades in Western Europe and the Soviet Union. Rendering plants are now installed in most floating factories.

Table XXVIII
Quantities of Fish Body Oils[a]
(1000 metric tons)

Area	1954/55	1955/56	1956/57	1957/58	1958/59	1959/60
World	339.0	335.0	282.0	303.0	369.0	386.0
United States	83.8	89.2	63.0	73.1	85.0	93.1
Alaska	72.2	76.3	53.7	58.1	70.2	83.2
Peru	1.2	3.0	7.7	10.0	23.7	48.2
Japan	40.9	15.6	26.3	30.7	37.9	25.0
West Germany	28.9	19.7	21.0	19.1	24.6	21.6
Soviet Union	17.1	10.4	10.3	12.0	16.9	20.7
Iceland	5.8	11.7	14.2	10.4	26.5	20.5

[a] Source: FAO Fisheries Yearbook.

Fish liver oils are provided by the Soviet Union, South Africa, the United Kingdom, etc.

South Africa produces vitamin A-potent liver oil from hake—largely a postwar industry. Four fifths of this production is shipped out to the United Kingdom, Norway, and the United States. Some is refined and used as human food in South Africa.

XXII. Factors in Utilization

A. Seasonality

In the United States 72% of the fish is landed in the second and third quarters. Without large-scale preserving in various ways it is not possible to efficiently used the ocean riches of salmon, menhaden, and herring. Very few efforts have been made to level out these large variations between months by developing more intensive fishing in off seasons or by employing new catch methods, by utilizing new, hitherto-neglected fish sources, or by moving into other areas during such down periods. This appears most vital to an efficient economic return on investment in ships and processing plants.

In West Germany there is also a semi-annual periodicity in the availability of fresh market fish. Excess quantities are encountered in March to June and deficits in the months of August to January (Meseck, 1959). Expanded freezing seems to offer the best possibilities for dealing with this discrepancy.

There is also a seasonality in consumption to overcome. In several countries summer use of fish is considerably less than in the winter. Summer heat affects the quality of fish. Even when improved refrigeration and modern large-scale preservation have entered the scene the traditional thinking lingers on and has its effect on the utilization pattern.

Religious fasting by several groups creates other irregularities in the weekly and yearly demand for fish, as well as the need for making seafood available at certain periods irrespective of catch sizes. Products with lengthened shelf life are most important as buffers.

B. Regionality

The regional discrepancies, particularly as between coastal and inland areas, still prevail in many countries, despite the availability of first-class preserved products. Tradition as well as price factors influence the persistence of this pattern. Both in Europe and the United States the coastal population shows higher figures for fish consumption than inland areas (Borgstrom, 1961a, Hass, 1961).

It is evident that countries with a well populated and extensive inland region and with less preferential distribution of its population to coastal regions would show higher percentages of consumption of processed fish products. The proportion of such manufactured items to the total fish consumed is lower in northern Germany than in the southern part (Hass, 1961).

C. Consumption Trends

Consumptional trends should also be listed here, although it is most difficult to separate such disposition from utilization trends. It can always be argued which comes first; this is very much a question of attitude and emphasis. It is most obvious that new, improved methods of processing and distribution do influence eating habits. This author is most inclined to give these utilization methods preference as driving forces. On the other hand, the gradual development of various consumption habits may become driving forces in accelerating certain trends and thus have a major impact on the prevailing utilization patterns. Some of the changes observed in fish consumption may, on the other hand, be common to all food, such as the desire and need for ready-made foods.

Among fundamental changes in western Europe and the United States which have affected consumption and exerted an influence on utilization methods, mention should be made of the following:

(*a*) Reduced sale of fresh whole fish.
(*b*) Increased demand for filleted or otherwise prepared fish.

(*c*) Ready-made fish products (fish soups, fish cakes, fish balls, fish sticks, etc.).

(*d*) Increased demand for fish and fish products which are more high-priced as average personal income has grown.

D. FISHING TRENDS

The general trend towards larger fishing vessels and more efficient fishing quite naturally has opened up opportunities for large-scale processing, as well as investments in improved handling and storage (icing, refrigerated holds, etc.). This is not the least significant factor working towards an improved utilization of the world's aquatic harvests. Possibilities have been created which were otherwise not available.

XXIII. Utilization Patterns in Selected Countries

A. JAPAN

The increase in Japanese production of processed fishery products has been remarkable. Processing into manufactured fishery products increased from 358,000 metric tons in 1956 to 440,000 tons in 1958. Canning used to dispose of around one-fourth million tons of fish. In 1961 this amount has almost doubled. The major cause of the swift growth in the processing of marine products is the severe international restrictions put on fishing operations in nearby waters which have forced many fishery companies to try to expand processing and move into distant waters. This in turn has induced a downward trend in the consumption of raw fish and a correspondingly larger demand for processed marine products.

B. UNITED KINGDOM

Total United Kingdom landings of whitefish have changed very little over the past 25 years except for a severe drop during the war years.

In 1923 the landings from distant waters by United Kingdom vessels represented less than a quarter of the total demersal fish landings. In the latter half of the 1920's and during the 1930's, Hull emerged as the largest fishing port in the United Kingdom, and concentrated on fishing distant water grounds. During the period 1923–1938 when total landings increased by approximately 50%, landings from distant water grounds rose by 250% and by 1938 over 60% of the demersal fish landed in the United Kingdom was caught by the distant water fleet. Over the past 10 years the proportion of fish landed from distant water grounds, although varying, has done so around an average of 70% of the total catch (Taylor, 1960).

A notable decrease has over the years taken place in the proportion of more expensive fish varieties, such as halibut, turbot, sole, plaice, etc., while varieties such as cod, haddock, saithe, and other coarse fish have mounted, chiefly as a result of the increasing dependence on the distant water catch.

C. ICELAND

Table XXIX shows the main categories of utilization of the Icelandic fish catch in 1958 and 1959.

TABLE XXIX
UTILIZATION OF ICELANDIC CATCH

	1958		1959	
	1000 metric tons	Percentage	1000 metric tons	Percentage
Whitefish (cod, ocean perch, etc.) (gutted fish)				
Fresh fish, landed in foreign ports	13	3.6	10	2.5
For freezing	236	62.1	258	64.9
For stockfish	45	11.7	42	10.5
For salting	69	18.1	77	19.5
Other (mostly reduction)	18	4.5	11	2.6
	381	100.0	398	100.0
Herring (weighed whole)				
Fresh (landed in foreign ports)	0	0.2	—	—
For freezing	15	6.7	16	14.9
For salting	36	20.0	53	49.8
For reduction	132	73.1	38	35.3
	183	100.0	107	100.0

As regards whitefish, no significant changes in the utilization have taken place. For many years now more than half and up to two-thirds of the catch of these species has been filleted and frozen almost entirely for export, and increased catches have continuously led to increased quantities being frozen, whereas quantities in other categories, such as stockfish and salted fish, have been fairly stable.

XXIV. Waste Utilization

In 1950 only half of the waste from U.S.S.R. fish-processing plants was being utilized. During the 1950's several efforts were made to improve on this situtation (Kudryavtsev, 1951).

An estimated 90 million lbs. of fish viscera are discarded annually by the Canadian Atlantic fisheries. From this amount about 18 million lbs. of visceral flour could be produced. Favorable experimental results on the use of such products have been reported from the Nappan Experimental Farm in Nova Scotia (Anonymous, 1953–1957).

In view of the increased shortage of horsemeat, salmon wastes have been tried successfully as an animal feed. They also are well suited as hatchery feed (Kyte, 1958). So far the viscera and trimmings from the Atlantic salmon industry have been poorly utilized, chiefly because the distances between plants are far too great to allow effective large-scale processing. The remoteness of purchasing markets is another factor.

An interesting new development is the use of offal meal and other by-products as feed in fish ponds. This is practiced in Denmark and Israel, among other places. The sizeable Danish production of rainbow trout requires no less than 45,000 tons of fish and offal (Nørgaard, 1961).

Most mussels captured in trawling used to be discarded in Soviet fishing, until special studies were conducted for a fuller utilization of the entire catch, including the invertebrates. Mussels were found to be particularly valuable (Kudryavtsev, 1951) (see also Chapter 2, Part II).

The fish oil obtained from the residues in the manufacturing of fish meal can be sulfated and used for specific purposes in the leather industry (Ceamis, 1958).

The normal raw material for fish-meal manufacture is of two kinds: (1) the waste from filleting operations, e.g., heads, skins and bones, and minor flesh pieces, and (2) surplus or condemned whole fish, or fish of species not usually eaten. There are two kinds of waste material which have so far been poorly utilized, namely fish guts and trawl refuse. Marketable fish are generally gutted at sea before being stowed away in ice, and the guts, apart from the livers, and any roe which may be present are generally thrown overboard; but they contain valuable nutrients and could be used (Lovern and Godden, 1950). By "refuse" is meant species of marine animals not generally brought to market but not infrequently captured in large amounts, particularly in trawling, such as starfish, sea urchins, anemones, shellfish of various kinds, and so on. This refuse is normally shoveled back into the sea.

In many countries there are at present efforts under way to utilize also these two sources. Starfish and urchins may render products with an excess of insoluble calcium-phosphate (see Chapter 9) and low in nitrogen.

XXV. Trade Patterns

A. General

Both in absolute and in relative terms Peru now has the lead among the fish-exporting countries of the world. Their deliveries to the global household was, in 1960, 592.23 thousand metric tons: 15.24 in canned fish, 18.13 frozen fish, 0.34 salt fish, 507.04 fish meal, 2.78 whale meal, 13.5 fish body oil, and 35.0 whale oil. This delivery represents approximately one-seventh of the total catch from the Pacific. In terms of protein this represents more than the entire Soviet catch, a sizeable 3.0 million metric tons.

Nevertheless it seems most enlightening to discuss food fish apart from the trade movements of fish meal and solubles. These latter commodities will be discussed separately (Section H).

The most conspicuous feature of the world trade pattern for food fish (see Table XXX) is the fact that the United States is leading the

TABLE XXX
TRADE IN FOOD FISH

	1958		1959	
Area	1000 metric tons	Percentage of total	1000 metric tons	Percentage of total
A. Imports[a]—Total	2029		2115	
United States	449.7	22.1	485.6	23.0
United Kingdom	186.7	9.2	197.1	9.3
West Germany	136.4	6.7	171.8	8.1
Italy	135.9	6.7	140.1	6.6
France	98.2	4.8	110.4	5.2
Soviet Union	111.3	5.5	106.3	5.0
Belgium	82.6	4.1	85.2	4.0
Denmark	58.3	2.9	73.6	3.5
Sweden	49.7	2.4	57.1	2.7
Hong Kong	58.3	2.9	52.4	2.5
Ceylon	51.7	2.5	49.5	2.3
Philippines	61.7	3.0	42.3	2.0
B. Exports—Total	2042.0		2136.0	
Norway	316.9	15.5	331.8	15.6
Japan	297.9	14.6	308.2	14.5
Canada	235.4	11.5	229.3	10.7
Netherlands	161.1	7.9	165.3	7.8
Iceland	156.2	7.7	155.0	7.3
Denmark	133.1	6.5	147.8	6.9
Portugal	72.6		81.2	
South Africa	63.8		68.1	
United Kingdom	44.3		48.1	
West Germany	43.6		46.1	
Soviet Union	25.3		45.0	
Peru	30.0		43.7	
Sweden	38.9		40.9	
Mexico	34.6		38.7	
France	38.3		38.4	
United States	29.6		36.1	

[a] Source: FAO Fisheries Yearbooks.

import market, its imports being about 2.5 times greater than those of any other country. Furthermore, this trend was persistently upwards during the entire 1950's. And this does not take into account the equally marked growth in the United States importation of fish meal.

In terms of total weight the list of importing nations is dominated by 10 nations. Only when reaching the tenth rank do protein-needy regions figure as buyers.

No clear distinction can be drawn between regular trade and the landing of catches in foreign ports. In principle these lots are equivalent both from the point of view of marketing economy and nutritional impact. The following tuna catches (in metric tons) were landed by Japanese fishing vessels in foreign countries in 1958. Although only a minor percentage of the entire catch of Japan, they are quite important to several of the recipient countries:

Italy	11,702	New Hebrides	3,648
Samoa	10,567	Haiti	2,650
Brazil	7,396	Trinidad	2,036
Panama	3,895	Cuba	1,688

Norway, which for a long time has been the leading exporter of food fish, is nowadays challenged in this position by Japan (Table XXX, B), rapidly surging ahead as a supplier of seafood to other nations in spite of its ever-growing population. More distinct characteristics of the global trade pattern of seafood emerge when the figures are broken down into more specific groups, following the subdivisions used in FAO statistics.

A. FISH: FRESH, CHILLED, OR FROZEN

This sector of international trade showed a considerable expansion during the 1950's, chiefly due to the freezing of fillets and whole fish.

The key position is held by the United States, the major receiver, accounting for one-third of all sales (see Table XXXI). Norway, Canada, Denmark, and Iceland are providing frozen fillets. Japan is supplying California plants with frozen tuna, partly packed in cans for subsequent heat processing.

The U.S.S.R. has increasingly been purchasing frozen fish fillets from Iceland and other countries.

Frozen fish has always been important in international trade. As far back as in the late 1880's, frozen fish from the United States was marketed in Hamburg. Frozen fish was delivered from Scandinavia and other European countries into the United States in the first part of this century. But the new era for this commodity is the postwar period and has been created chiefly by the large bulk deliveries from Canada

(Newfoundland) and Norway to the United States market (Borgstrom, 1961a, b), mainly cod, haddock, and other whitefishes, and the large purchases of frozen herring by the Soviet Union and by eastern Europe from western European nations, chiefly the United Kingdom, Norway, and Sweden. Denmark is selling fresh market plaice and frozen fillets of plaice and cod as well as frozen whole herring.

TABLE XXXI

TRADE IN FRESH, CHILLED, OR FROZEN FISH

Area	1958		1959	
	1000 metric tons	Percentage of total	1000 metric tons	Percentage of total
A. Imports—Total	842.3	100.0	883.3	100.0
United States	258.6	30.7	264.7	30.0
West Germany	96.1	11.4	126.2	14.3
United Kingdom	101.1	12.0	98.9	11.2
Denmark	63.5	7.5	68.0	7.8
Soviet Union	56.1	6.7	53.6	6.1
Italy	42.6	5.1	47.0	5.3
B. Exports—Total	844.9	100.0	891.1	100.0
Japan	144.9	17.1	143.2	16.1
Norway	125.8	14.9	149.1	15.2
Canada	134.0	15.8	133.3	15.0
Denmark	114.5	13.6	125.1	14.0
Iceland	89.2	10.6	94.3	10.6

China entered the international fish trade at the end of the 1950's selling to western Europe (West Germany and the United Kingdom) chiefly frozen fish but also canned fish, fish roe, fish paste, etc. The 1960 purchase by the United Kingdom exceeded one million dollars in value.

In terms of protein, fresh, chilled, or frozen fish represent one-fifth of the total amount moving in world trade channels (see Table XXXII) (see further Borgstrom, 1963c).

TABLE XXXII

SEAFOOD COMMODITY IN INTERNATIONAL TRADE (1958–1959 AVERAGE)[a]

Commodity	1000 metric tons	%
Fish: fresh, chilled, and frozen	85	21.6
Fish: dried, salted, or smoked	206	52.5
Crustaceans and mollusks: fresh, dried, and salted	40	10.4
Canned seafood	58	14.8
Special seafood preparations	4	0.7
	393	100

[a] In terms of protein.

C. Fish: Dried, Salted, or Smoked

It was emphasized in Chapter 7 that dried cod and other related fishes, together with salted herring, constitute the most important vehicle for conveying fish protein to protein-needy areas such as the Mediterranean, Italy, Spain, Greece, the Caribbean, and tropical Africa (see also Borgstrom, 1951).

Deviating from this general pattern are the purchases of salted herring by the U.S.S.R., accounting for about one-tenth of its fish intake. The United States also buys salted herring to satisfy the demand by those of Scandinavian background, and other ethnic groups.

Table XXXIII

Trade in Dried, Salted, or Smoked Fish

	1958		1959	
Area	1000 metric tons	Percentage of total	1000 metric tons	Percentage of total
A. Imports—Total	539.2	100.0	511.6	100.0
Italy	65.1	12.1	57.7	11.3
Soviet Union	55.1	10.2	52.7	10.3
Ceylon	45.2	8.4	43.0	8.4
United States	39.8	7.4	39.7	7.8
Nigeria	29.2	5.4	na[a]	na[a]
Congo (Belgium)	24.2	4.5	22.8	4.4
Spain	18.9	3.5	17.9	3.5
West Indies	18.1	3.4	na[a]	—
Greece	17.0	3.2	17.2	3.4
B. Exports—Total	534.0	100.0	516.2	100.0
Norway	149.1	27.9	134.5	26.1
Canada	66.1	12.4	61.7	12.0
Iceland	66.4	12.4	60.2	11.7
Netherlands	45.3	8.5	41.8	8.1
France	26.4	4.9	25.0	4.8
India	22.5	4.2	22.9	4.4
United Kingdom	21.7	4.1	27.2	5.3

[a] Figures not available.

More than one-fourth of the cured fish, chiefly stockfish and klippfish and some salted herring, is provided by Norway (see Table XXXIII). Cured cod is furnished by Canada, Iceland, and France, salted herring by Norway, the Netherlands, Iceland, and the United Kingdom. Half of the export from the Faeroe Islands consists of klippfish and salted fish, supplying Brazil and the Mediterranean.

A great number of cured products are being produced, particularly in Southeast Asia, and play a remarkable part in the trade and feeding of critical areas. Dried fish is being exported from the state of Kerala (southern India) to Ceylon and Burma. Ceylon obtains from the Maldive Islands a specially cured product, Maldive fish, making her imports 25,000 to 35,000 metric tons per year—equivalent to 70,000 to 100,000 tons in fresh weight. China is also providing dried fish. Next to rice and wheat flour, dry fish is the most important item among Ceylon's food imports.

Prior to the war, extensive trade in cured fish took place from Thailand and Indochina to Singapore, some of which was re-exported to Indonesia. This trade moving through the focal center of Singapore amounted to some 50,000 metric tons per year, representing about 150,000 metric tons of fresh fish. During the war and immediate postwar years this trade was drastically curtailed. It has resumed some size during the 1950's but has not yet reached the prewar level. Indochina produces sizeable quantities of fermented pastes and sauces, but the data on these are not adequate to provide a picture of the magnitude of the amount of raw materials used or of products manufactured.

As a whole, cured products—salted and dried—figure prominently in the international movement of high-class animal protein. In terms of protein quantities, cured products account for more than 62% of the international trade, 52% of which is fish and 10% shellfish (Table XXXII).

D. CRUSTACEANS AND MOLLUSKS: FRESH, DRIED, AND SALTED

These items play an insignificant part in the world trade. In effect, only two transactions are essential, namely, the delivery of mussels to Belgium from neighboring Netherlands and the sale of shrimp to the United States, primarily as a raw material for subsequent reprocessing by freezing or canning (see Table XXXIV).

TABLE XXXIV
TRADE IN CRUSTACEANS AND MOLLUSKS: FRESH, DRIED, SALTED

	1958		1959	
Area	1000 metric tons	Percentage of total	1000 metric tons	Percentage of total
A. Imports—Total	184.1	100.0	215.7	100.0
United States	65.6	35.6	79.1	36.7
France	35.7	19.4	41.6	19.3
Netherlands	5.5	3.0	18.5	8.6
B. Exports—Total	165.5	100.0	192.9	100.0
Netherlands	54.1	32.7	61.4	31.8
Mexico	26.8	16.2	30.5	15.8
Japan	10.7	6.5	13.0	6.7

E. CANNED SEAFOOD

The United Kingdom and the United States between them receive slightly above one-third of the world's export of canned seafood (see Table XXXV). In spite of the large tuna and salmon packs, these items do not figure heavily in the world market. Sardines of various kinds are dominating (about 40% of total) by the sales of Portugal, South Africa, Morocco, and Norway.

TABLE XXXV
TRADE IN CANNED FISH AND SHELLFISH

Area	1958		1959	
	1000 metric tons	Percentage of total	1000 metric tons	Percentage of total
A. Imports—Total	422.7	100.0	448.9	100.0
United Kingdom	75.5	17.9	84.6	18.8
United States	74.6	17.6	79.3	17.7
Philippines	61.7	14.6	42.3	9.4
Italy	24.6	5.8	30.7	6.8
West Germany	24.8	5.9	29.9	6.7
France	18.9	4.5	29.1	6.5
B. Exports—Total	483.6	100.0	509.2	100.0
Japan	137.2	28.5	146.3	28.8
Portugal	66.2	13.6	75.2	14.8
South Africa	48.6	10.0	47.7	9.4
Morocco	31.4	6.5	34.1	6.7
Norway	39.1	8.1	30.6	6.0
United States	18.1	3.7	30.2	5.9
Canada	35.3	7.4	21.9	4.3
Soviet Union	11.7	2.4	20.5	4.0
Peru	13.3	2.8	17.5	3.4
C. Type of Exports				
Sardine, herring, etc.	191.6	39.6	226.0	44.4
Pacific Salmon	90.5	18.8	88.5	17.4
Tuna, bonito, mackerel, etc.	63.5	13.1	66.5	13.1
Crustaceans and mollusks	24.0	5.0	29.6	5.8

Most canned seafood is used to enrich the diet of well-fed nations; only minor quantities constitute essential foods to poorly nourished countries. In this latter respect there is a fundamental difference between canning and drying, as is evident from the data given in Section C. Japan is the largest exporter of canned crab meat. The Soviet excess pack is shipped mainly to the United States, France, the United Kingdom, and Sweden.

TABLE XXXVI
TRADE BALANCE OF FISH PROTEIN

	Fish protein in trade (metric tons)			Annual consumption of fish protein (metric tons)	Imported or exported fish protein as percentage of consumption
Area	1958	1959	1958/59		
		A. Net Importation			
Cuba	6,102	5,784	5,843	1,700	343.7
Ceylon	23,605	22,635	23,120	9,900	231.0
Austria	3,021	3,180	3,101	1,900	163.5
Belgium	16,472	16,918	16,695	11,400	147.0
West Indies	9,642	9,500	9,571	9,800	97.5
Israel	3,984	2,265	3,125	3,358	93.8
Dominican Republic	2,860	2,925	2,893	3,088	93.7
Mozambique	2,237	na[a]	2,237	2,600	86.0
Greece	9,260	9,879	9,570	11,200	85.7
Liberia	520	530	525	620	84.7
Italy	42,054	39,994	41,023	51,000	80.5
Switzerland	2,015	2,245	2,130	3,057	70.0
Egypt	1,538	1,726	1,632	23,800	68.6
Rhodesia & Nyasaland	1,789	1,949	1,869	2,800	66.8
Ghana	3,534	3,095	3,315	5,013	66.1
Australia	4,379	3,272	3,826	7,000	54.7
Congo (Belgium)	13,412	12,898	13,055	24,400	53.5
El Salvador	125	45	85	165	51.5
United States	75,690	80,975	78,333	163,800	47.8
Brazil	8,115	7,780	7,948	26,000	30.3
Finland	2,329	1,604	1,667	5,650	29.6
Sweden	7,329	5,917	6,623	22,400	29.6
Malaya	3,600	3,420	3,515	13,500	26.1
France	5,944	9,766	7,505	46,400	16.2
United Kingdom	12,911	14,603	13,757	85,300	16.2
Philippines	9,240	6,330	7,785	56,200	13.8
Indonesia	13,490	8,236	10,863	79,200	13.7
West Germany	7,551	9,867	8,709	75,600	11.5
Venezuela	724	12,527	19,170	252,000	7.6
Soviet Union	25,812	784	754	7,500	10.0
Burma	3,220	3,080	3,050	58,200	5.2
Vietnam	440	836	638	12,500	5.1
Spain	2,089	2,342	2,016	53,300	3.8
		B. Net Exportation			
Norway	94,238	90,818	92,528	12,336	750.0
Netherlands	39,717	34,308	37,014	9,700	381.0
Canada	54,247	50,163	52,205	23,600	221.2

TABLE XXXVI (*continued*)

Area	Fish protein in trade (metric tons)			Annual consumption of fish protein (metric tons)	Imported or exported fish protein as percentage of consumption
	1958	1959	1958/59		
	B. Net Exportation (*continued*)				
Panama	505	515	510	262	194.6
Denmark	10,350	12,637	11,494	9,448	114.8
Morocco	6,290	6,987	6,639	5,800	114.5
Iceland	2,201	2,218	2,210	2,183	101.0
Mexico	7,347	8,287	7,817	8,500	92.0
Yugoslavia	1,925	1,366	1,646	2,100	78.2
Iran	1,200	1,046	1,143	1,500	75.4
Tunisia	414	545	470	710	66.2
South Africa	10,175	10,856	10,516	22,500	46.7
Angola	7,494	6,715	7,105	25,950	27.4
Cambodia	2,750	2,384	2,517	10,441	24.1
Portugal	5,342	9,144	7,043	45,100	15.5
Japan	40,876	43,549	42,213	384,800	10.9
New Zealand	151	435	293	3,132	9.4
Turkey	650	653	652	6,800	9.6
Pakistan	5,191	7,751	6,471	70,400	9.2
Colombia	20	250	230	3,600	6.4
Peru	2,959	4,155	3,557	10,800	3.3
Thailand	7,511	3,321	5,416	170.3	3.1

[a] Figures not available.

F. Aquatic Oils and Fats

Leading products in this category are whale oil, cod liver or shark oil, herring oil, and menhaden oil. Aquatic oils constitute important raw material to the oleomargarine industry of several Western countries (see Table XXVII and Section XXI).

Norway and Japan contend for the leading position as exporters of aquatic oils, together accounting for almost half the world trade in these items. The United States comes third in line.

G. Imports in Food Balance

From the foregoing analysis of the world trade in seafood and the part played by alternative utilization channels, it is most evident that product weight is an unsatisfactory basis for evaluating the nutritional significance of this seafood trade. For this reason the protein quantities moving in the different channels have been computed (see Table XXXVI).

In addition, the amount of fish protein made available by each net exporting country, and the quantity received by each net importing country, has been related to the intake of fish protein in that country. Thus, the last column of Table XXXVI gives the net trade quantity as a percentage of total consumption of fish protein. With respect to imported fish protein, these figures show in each case how essential is this influx. With respect to net exports, they indicate the impact of the exporting country's catch—e.g., the exports of Norway can provide fish protein (on a consumption level the equivalent of Norway's) to a population 7.5 times that of Norway, i.e., some 26 million people. Actually, however, some 300–500 million eat Norwegian fish products. On considering the cheapness of dried fish and salted herring, and the low protein standards of the recipient countries of Africa and Latin America, the Norwegian exports take on major significance. On a global scale they are vital to the world protein provision. Correspondingly this is true of the contributions by the Netherlands and Canada and Denmark, although on a slightly lower level. The Panama export is constituted by shrimp sold to the United States. It is worth noting that Denmark is offering the world market an amount of fish protein slightly above what its entire population is eating.

A few incongruities in these calculated figures of Table XXXVI require comment. In some developed countries the imports appear higher than the known conditions would seem to indicate. This can only be resolved by further investigation but may be due to the fact that part of the imported seafood is used for other purposes than human food, such as pet food, bait fish, feed in fish cultivation, or for the feeding of fur animals. Another case seems represented by Cuba, etc., where the importation by far exceeds the computed total consumption. On assuming that these figures for total consumption are correctly computed, there is in all these cases the obvious likelihood that available consumption data are deficient and that the per capita intake of fish has been grossly underrated. Spoilage of this magnitude or long-term storage appear to be less likely explanations. Even in these countries some items may nevertheless be used for other purposes than human feeding.

H. FISH MEAL AND SOLUBLES

The key position of fish meal in the animal production of the world —chiefly within the well-fed nations—seems to be poorly understood. Table XXXVII, and Table XXXVIII, computed by the author on the basis of FAO Food Balance figures, bring out in a most conspicuous way the profound consequences of even a minor adjustment in the present utilization pattern of fish meal. If the meal were only partially

TABLE XXXVII
TRADE IN FISH MEAL AND SOLUBLES[a]

Area	Amount (1000 metric tons)				Percentage of total	Cumulative sum, Σ	
	1958	1959	1960	1961		Weight	Per cent
A. Imports—Total	605	760	1000	1160			
West Germany	124.3	150.6	192.0	200.0	17.5	—	—
United Kingdom	115.2	149.5	168.0	165.0	14.2	365.0	31.7
United States	104.2	144.8	127.3	130.0	11.2	495.0	42.9
Netherlands	84.4	100.6	134.0	125.0	10.8	620.0	53.7
France	42.2	39.8	34.0	55.0	4.7	675.0	58.4
East Germany	na[b]	na[b]	40.0	50.0	4.3	725.0	62.7
Belgium	28.2	29.9	48.0	50.0	4.3	775.0	67.0
Italy	14.4	13.3	30.6	35.0	3.0	810.0	70.0
Japan	na[b]	na[b]	19.4	30.0	2.7	840.0	72.7
Switzerland	13.2	15.4	22.0	25.0	2.4	865.0	75.1
Sweden	11.5	18.7	17.5	21.0	1.8	886.0	76.9
Israel	20.2	12.1	14.6	20.0	1.7	906.0	78.6
B. Exports—Total	605	760	1000	1160			
Peru	105.8	278.1	378.0[c]	600.0	51.7	—	—
South & southwest Africa	89.4	99.4	117.0	140.0	12.1	740.0	62.8
Norway	106.9	89.2	108.0	110.0	9.5	850.0	72.3
Iceland	54.5	43.7	54.3	60.0	5.2	910.0	75.5
Chile	10.9	16.5	30.0	55.0	4.7	965.0	80.2
Malaya	81.2	51.2	49.0	50.0	4.3	1015.0	84.5
Canada	28.9	49.6	35.0	40.0	3.5	1055.0	88.0
Denmark	53.5	58.8	31.8	35.0	3.0	1090.0	91.0
Africa	50.0	15.0	140	205.0			
South America	60.0	660.0	660.0				

[a] Source: FAO statistics.

[b] Figures not available.

[c] According to Paz Andrade (1962), 507,042 in 1960.

transferred from livestock and poultry to direct human consumption, and in this way upgraded, enormous savings of nutrients would ensue. This need not necessarily be done by the elaborate manufacture of fish flour; a cheaper and more efficient way would be by improving the methods for a direct preservation of the raw products (drying, fermenting, freezing) or by introducing more lenient methods in the manufacture of meal. This particular aspect will be discussed in Volume III, Chapter 24.

TABLE XXXVIII

FISH MEAL BALANCE IN 1960 (1000 METRIC TONS)

Area	Production	Import	Total	Export	Net
United States	358.3	130.0	488.3	—	488.3
West Germany	82.5	192.0	274.5	5.0	269.5
United Kingdom	76.2	168.0	244.2	—	244.2
Netherlands	13.0	134	147.0	2.0	145.0
Belgium	8.0	48.0	54.0	2.0	52.0
Norway	156.0	—	156.0	108.0	48.0
Spain	48.7	—	48.7	—	48.7
Denmark	50.0	18.8	68.8	31.8	37.0
Sweden	5.0	17.5	22.5	1.0	21.5
Japan	281.7	19.4	301.1	6.2	294.9
Soviet Union	63.0	—	63.0	—	63.0
South & southwest Africa	152.3	—	152.3	117.0	35.3
Israel	—	14.6	14.6	—	14.6

Such a large-scale upgrading would be conducive to substantial improvements in the nutritional standards of Africa and South America, for fish meal protein is now largely siphoned off from these two protein-critical continents. It is a most notable fact that Africa needs per year some 950,000 metric tons of protein and Latin America some 1,250,000 metric tons to reach a satisfactory protein level from the nutritive point of view. Fish meal protein would actually go a long way towards filling these needs.

The agriculturists of the United States, western Europe, and Japan are evidently not aware of the degree to which their present flourishing animal production is influenced by the tremendous and inobscure influx of high-class protein (see Table XXXIX).

No other utilization problem in the field of fish is as important as fish meal production. Almost any other measure in the traditional channels of fish preservation appears insignificant compared to the dominance and general impact of this single factor. Fish protein accounts for 14.8–99.0%

TABLE XXXIX

FISH PROTEIN IN FISH MEAL IN RELATION TO INTAKE OF ANIMAL PROTEINS

Area	Non-fish animal protein intake				Fish meal protein used (metric tons)	Percentage of animal production due to fish protein	% Fish meal imported	% Animal production due to imported fish meal
	Population (millions)	Grams/day		Metric tons/ year				
West Germany	55.0	A[a]	38.9	780.9	269.5	6.9	70	4.8
		B	11.8	239.5		22.5		15.7
United Kingdom	52.2	A	44.6	849.8	242.2	5.8	69	4.0
		B	7.2	137.3		35.2		24.5
Netherlands	11.3	A	40.5	167.0	145.0	17.4	30	15.7
		B	8.1	32.9		88.6		79.5
Belgium	9.1	A	40.5	134.5	52.0	7.7	89	6.9
		B	12.1	40.2		25.9		23.0
Norway	3.4	A	40.9	50.8	48.0	18.9	—	—
		B	7.8	9.7		99.0		—
Spain	29.9	A	15.3	167.0	48.7	5.7	—	—
		B	4.9	53.2		18.3		—
Denmark	4.5	A	49.0	80.5	37.0	9.2	27	2.5
		B	13.4	22.1		37.5		0.2
Sweden	7.4	A	49.9	134.8	21.5	3.2	78	2.5
		B	10.7	28.9		14.8		11.5
Japan	95.0	A	4.0	138.7	294.9	42.5	6.4	2.7
		B	1.9	55.9		105.8		6.8
Israel	2.0	A	26.8	19.6	14.6	14.9	100.0	14.9
		B	8.1	6.0		48.8		48.8
South and southwest Africa	15.2	A	25.1	139.2	35.3	5.1	—	—
		B	2.3	12.7		55.6		—
United States	177.7	C	10.8	700.5	488.3	23.2[b]	26.6	3.7
		D	4.4	285.4		57.2		9.1

[a] Key: A, total non-fish animal protein. C, poultry meat and eggs. B, pork, poultry meat, and eggs. D, poultry meat.

[b] Conversion factor 1/3.

of total non-fish animal protein. In countries such as Norway, Denmark, and West Germany, the percentage is still higher, since fish silage is not included in this survey. Furthermore, it is known that, in Norway, for example, some fish meal goes into milk production; this is also true of Japan. It must, however, be borne in mind that some of the available fish is utilized as feeding stuff for the raising of fur animals.

In the United States almost all fish meal goes into poultry feeds and the production of broilers. This justifies the use of a more favorable conversion efficiency factor in this case, 1:3 instead of 1:5. From this kind of appraisal, the sea is considered a dominant factor in the production of broilers in the United States—theoretically fish account for almost the entire production in terms of protein.

The data for Japan reveal that more than 40% of the animal production of that country is dependent on fish. The amount of fish protein employed for this purpose is more than twice as large as the total intake of non-fish animal protein.

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LIST OF COMMON FOOD FISHES

This list comprises the most important economic (commercial) species of the world's ocean and major fresh-water fishes.

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English	Latin
Alaska pollock	See pollock, Alaska
Albacore (Atlantic)	*Seriola lalandi* Valenciennes
Albacore (Pacific), syn. long-finned tuna	*Thunnus alalunga* Bonnaterre
Alewife (Europe), syn. Allis shad, shad, rock herring	*Clupea* (*Alosa*) *alosa* Linnaeus
Alewife (United States, Canada)	*Pomolobus pseudoharengus* (Wilson) and *P. aestivalis* (Mitchill)
Alfonsino	*Beryx splendens* Lowe
Amberfish (America)	See Atlantic albacore
American plaice, syn. long rough dab	*Hippoglossoides platessoides* (Fabricius)
Anchovy (Australia)	*Engraulis australis* White
Anchovy (Azov Sea)	*Engraulis encrasicholus maeoticus* Pus.
Anchovy (Black Sea), syn. "Chamsa" (Russian)	*Engraulis encrasicholus ponticus* (Linnaeus)
Anchovy (European)	*Engraulis pseudoharengus* (Wilson), syn. *Engraulis encrasicholus* Linnaeus
Anchovy (Japanese)	*Engraulis japonicus* (Houttuyn)
Anchovy (Indian)	*Anchoviella indica* (van Hasselt), syn. *Engraulis* (*Stolephorus*) *indicus* Bleeker
Anchovy (Malayan)	*Stolephorus* spp.
Anchovy, northern (East Pacific)	*Engraulis mordax* (Girard)
Angelfish (Europe)	See monkfish
Angelfish (United States)	*Pomocanthus* and *Holocanthus* spp.
Angler, syn. lesser weever, stingfish	*Trachinus vipera* Cuvier and Valenciennes
Angler (Japan)	*Lophius litulon* Jordan
Angler (Northwest Atlantic), syn. goosefish	*Lophius americanus* Cuvier and Valenciennes
Anglerfish (United Kingdom), syn. monkfish, fishing frog, or silver salmon	*Lophius piscatorius* Linnaeus
Arctic char	*Salvelinus alpinus* Linnaeus
Arctic cisco	*Coregonus autumnalis* Pallas

English	Latin
Arctic cod	See polar cod
Arctic flounder	See polar plaice
Arctic grayling	*Thymallus arcticus* Pallas
Argentine (Atlantic)	*Argentina silus* Ascanius
Argentine (Pacific)	*Argentina sialis* Gilbert
Arrow-toothed flounder, arrow-toothed halibut	*Atheresthes stomias* (Jordan and Gilbert)
Atherine	See smelt (sparling)
Atka mackerel	*Pleurogrammus azonus* Jordan and Metz, syn. *P. monopterygius* (Pallas)
Atlantic round herring	See herring (Caribbean)
Atlantic tuna	See blackfin tuna
Atlantic wolf-fish, syn. catfish	*Anarhichas lupus* Linnaeus
"Ayu" (Japanese)	*Plecoglossus altivelis* Temminck and Schlegel
Barbel	*Barbus barbus* (Linnaeus)
Barracouta (Australia)	*Thyrsites atun* (Euphrasen)
Barracuda, syn. sea pike	*Sphyraena* spp.
Barracuda (Japanese)	*Sphyraena picuda* Bloch and Schneider
Bass (Atlantic), syn. salmon bass	*Morone labrax* (Linnaeus), syn. *Labrax lupus*
Bass, common (Japan)	*Nipon spinosus* Cuvier
Bass, striped	*Roccus saxatilis* (Walbaum)
"Beluga" (Russia)	See sturgeon (Danube)
Bib, syn. pout, pouting	*Gadus luscus* Linnaeus
Bighead	*Aristichthys nobilis* (Richardson)
Bigmouth, syn. bufflalofish, winter carp	*Megastomatobus cyprinella* (Cuvier and Valenciennes)
Black cod	*Erilepis zonifer* Linnaeus
Black sea bass	See giant sea bass
Blanquillo	*Branchiostegus* spp.
Blenny	*Enedrias nebulosus* (Temminck and Schlegel)
Bluefin tuna, syn. blackfin tuna, tunny	*Thunnus thynnus* (Linnaeus)
Bluefish	*Pomatomus saltatrix* (Linnaeus)
Bluegill	*Lepomis macrochirus* Rafinesque, syn. *Helioperca incisor*
Blue ling	See ling, blue
Blue mackerel	See Pacific mackerel
Blue pike	See blue walleye
Blue walleye	*Stizostedion vitreum glaucum* (Hubbs)
Blue whiting	See poutassou
Bluet	See skate
Bonito (Atlantic)	*Sarda sarda* Bloch
Bonito (Australia)	*Sarda australis*
Bonito (California)	*Sarda lineolata* (Girard)

English	Latin
Bonito (Pacific)	*Sarda chilensis* (Cuvier and Valenciennes)
Bonito, ocean	See skipjack
Bonito, plain	*Orcynopsis unicolor* (St. Hilaire)
Bonito, striped, syn. Oriental bonito	*Sarda orientalis* (Temminck and Schlegel)
Bordered skate	See skate, owl
Bowfin	*Amia calva* Linnaeus
Bream, fresh-water	*Abramis brama* Linnaeus
Bream, Ray's	See pomfret
Bream, sea (West Atlantic)	*Lagodon rhomboides* (Linnaeus)
Bream, sea (East Atlantic)	See sea bream
Brill (North Sea)	*Rhombus laevis* (Rondelet), syn. *Scophthalmus rhombus* Linnaeus
Brill (Northwest Atlantic)	*Lophopsetta maculata* (Mitchill)
Brill (Pacific)	See petrale sole
Brill (Oceania)	*Colistium güntheri* (Hutton)
Brisling	See Scandinavian sardine
Brook trout	*Salvelinus fontinalis* (Mitchill)
Brown trout	*Salmo trutta* Linnaeus
Buffalofish	See bigmouth
Bullhead	See catfish (fresh-water)
Burbot, syn. "nalim" (Russia)	*Lota lota* (*lacustris*) (Walbaum)
Butt	See flounder (Europe)
Butterfish	*Poronotus triacanthus* (Peck)
Butter sole	*Isopsetta isolepis* (Lockington)
Cape salmon	See geelbek, may also be *Elops saurus* Linnaeus
Capefish	See horse mackerel
Capelin (Arctic)	*Mallotus catervarius* (Pennaut)
Capelin (Atlantic)	*Mallotus villosus* (Müller)
Capeline (Pacific)	*Mallotus socialis* (Pallas)
Carp, common	*Cyprinus carpio* Linnaeus
Carp, crucian, syn. German (or Prussian) carp	*Carassius carassius* (Linnaeus)
Caspian lamprey	*Caspiomyzon wagneri* Kessler
Caspian roach	*Rutilus rutilus caspicus* (Jakimov)
Caspian sturgeon	See "sevruga"
Catfish (fresh-water)	*Ictalurus* spp., syn. *Pilodictis olivaris* Rafinesque
Catfish, banded	See Atlantic wolf-fish
Chain pickerel	*Esox niger* LeSueur
Char (Arctic)	See Arctic char
Char (Great Lakes)	*Salvelinus* (*Cristivomer*) *namaycush* (Walbaum)
Cherry salmon	*Oncorhynchus masou* (Brevoort)
Chinook salmon	See king salmon
Chub (North America)	*Leucichthys* spp.
Chub (Columbia River)	See peamouth

English	Latin
Chub mackerel	See Pacific mackerel
Chum salmon	*Oncorhynchus keta* (Walbaum)
Cigarfish	See round scad
Cisco	*Coregonus* (*Leucichthys*) *artedi* (LeSueur)
Coalfish	*Pollachius* (*Gadus*) *virens* (Linnaeus)
Cod (Atlantic), codling	*Gadus callarias* (Linnaeus), syn. *Gadus morhua* Linnaeus
Cod (Korean)	See pollock (Alaska)
Cod (Pacific)	*Gadus* (*morhua*) *macrocephalus* Tilesius
Coho salmon	See salmon, silver
Coley	See coalfish
Conger eel (Northwest Atlantic)	*Conger oceanicus* (Mitchill)
Conger eel (North Atlantic)	*Conger conger* (Linnaeus)
Conger eel (Northwest Pacific)	*Astroconger myriaster* (Brevoort)
Corsair	See Rockfish, rosy (Northeast Pacific)
Crappie	*Pomoxis* spp.
Croaker (Atlantic)	*Micropogon undulatus* (Linnaeus)
Cusk	*Brosme brosme* (Müller)
Cutlass fish	See scabbard fish
Cutthroat trout (Northwest Atlantic)	*Salmo clarki* (Richardson)
Dab (Europe)	*Limanda limanda* (Linnaeus)
Dab, long rough	See American plaice
Dab (Atlantic), longhead	*Pleuronectes* (*Limanda*) *ferruginea* (Linnaeus)
Dab (Oceania)	*Rhombosolea plebeia* (Richardson)
Dab (West Pacific)	See yellowfin sole
Dace (Northwest Pacific)	*Tribolodon hakonensis hakonensis* (Günther)
Danube sturgeon	See beluga (Russia)
"Dara"	See Indian salmon
Dogfish (Atlantic and Pacific)	*Squalus acanthias* Linnaeus, syn. *Sq. suckleyi* (Girard)
Dogfish, greater spotted	*Scylliorhinus stellaris* Linnaeus
Dogfish, Japanese	*Squalus mitsukurii* Jordan and Fowler
Dogfish (South Africa)	*Scylliorhinus capensis* (Müller and Hente)
Dogfish, smooth (American)	*Mustelus canis* (Mitchill)
Dogfish, smooth (European)	*Mustelus mustelus* Linnaeus
Dogfish, smooth-hound	*Emissola antarctica* (Günther)
Dogfish, (fresh-water)	See bowfin
Dog salmon	See chum salmon
Dolly Varden	*Salvelinus malma* (Walbaum)
Dolphin, syn. dorado	*Coryphaena hippurus* Linnaeus
Dover slime sole, syn. Dover sole (Northeast Pacific)	*Microstomus pacificus* (Lockington)
Dover sole	See sole (European)

English	Latin
Drum (fresh-water)	*Aplodinotus grunniens* (Rafinesque)
Eel (North America)	*Anguilla rostrata* (LeSueur)
Eel (Australia)	*Anguilla aucklandii* Philippi
Eel (Europe)	*Anguilla anguilla* Linnaeus
Eel (Japan)	*Anguilla japonica* Temminck and Schlegel
Electric ray	*Torpedo* spp.
Elephant fish (Nile)	*Mormyrus oxyrhynchus*
English sole (Northeast Pacific)	*Parophyrys vetulus* (Girard)
Eulachon	*Thaleichthys pacificus* (Richardson)
Fiddle fish	See angelfish
Flake, syn. huss or rigg	Various dogfish
Flatfish, "hirame" (Japan)	See starry flounder
Flathead (Australia)	Species of *Platycephalus, Neoplatycephalus, Trudis,* and *Leviprora*
Flathead (Pacific)	*Platycephalus indicus* Linnaeus
Flathead sole	*Hippoglossoides classodon* Jordan and Gilbert
Flounder (Europe)	*Pleuronectes flesus* Linnaeus
Flounder (Oceania)	*Rhombosolea* spp.
Fluke	See flounder (Europe)
Flying fishes	*Cypselurus* species (several), *Prognichthys agoo* Temminck and Schlegel, and *Hirundichthys affinis* (Günther)
Forkbeard, greater	*Phycis* (*Urophycis*) *blennoides* (Brünnich)
Forked hake	See forkbeard, greater
Fresh-water drum	*Aplodinotus grunniens* (Rafinesque)
Frigate mackerel	*Auxis thazard* (Lacépède)
Furnard	See gurnard
Garfish (Atlantic)	See gar pike
Garfish, sea (Australia)	Species of *Heporhamphus, Arrhamphus,* and *Hemirhamphus*
Gar pike	*Belone belone* Linnaeus
Geelbek	*Atractoscion aequidens* Cuvier
"Ghol"	See jewfish (India)
Giant sea bass	*Stereolepis gigas* Ayres
Gilthead	*Chrysophris auratus* (Bloch and Schneider)
Gizzard shad	*Dorosoma cepedianum* (LeSueur)
Globefish	*Sphaeroides* spp.; see also puffers
Grass carp	*Ctenopharyngodon idella* (Cuvier and Valenciennes)
Goldfish	*Carassius auratus* Linnaeus
Goosefish	See angler (Northwest Atlantic)
Gray cod	See cod (Pacific)
Gray mullet	See mullet, gray

English	Latin
Gray skate	See skate
Grayling (fresh-water) (North America and Europe), syn. Arctic grayling	*Thymallus arcticus* (Pallas) and *Thymallus thymallus* (Linnaeus)
Great blue shark	*Prionace glauca* (Linnaeus)
Great weever	*Trachinus draco* Linnaeus
Greenfish	*Girella punctata*
Greenland cod	*Gadus ogac* Richardson
Greenland halibut	*Reinhardtius hippoglossoides* (Walbaum)
Greenland shark	*Somniosus microcephalus* (Bloch and Schneider)
Grenadier	See rattail
Grouper (Oceania), syn. "hapuku" (Australia)	*Polyprion oxygeneios* (Bloch and Schneider)
Grouper (Atlantic)	*Epinephelus* spp.
Guppy	*Girardinus guppyi*
Gurnard	*Trigla* spp.
Gurnard (South Africa)	*Trigla capensis* Cuvier
Gurnard, red (Japan)	*Chelidonichthys* (*Trigla*) *kumu* (Lesson and Garnot)
Gwyniad	See powan
Haddock (Atlantic)	*Melanogrammus* (*Gadus*) *aeglefinus* Linnaeus
Hairtail (Atlantic)	*Scabbard fish* (Northwest Atlantic)
Hairtail (Japan)	*Trichiurus japonicus*
Hake (Atlantic)	*Merluccius merluccius* Linnaeus
Hake (Oceania)	*Merluccius gayi*
Hake (Pacific)	*Merluccius productus* Ayres
Hake (South Africa)	See stockfish
Halfbeak (Japanese)	*Hemiramphus sajori* Temminck and Schlegel
Halibut (Atlantic)	*Hippoglossus hippoglossus* (Linnaeus) syn. *H. vulgaris*
Halibut (Pacific)	*Hippoglossus stenolepis* (Schmidt)
Hammerhead (shark)	*Sphyrna zygaena* (Linnaeus)
Herring (Atlantic)	*Clupea harengus harengus* Linnaeus
Herring (Pacific)	*Clupea harengus pallasii* (Cuvier and Valenciennes)
Herring (Oceania)	*Aldrichetta forsteri* Cuvier and Valenciennes
Horse mackerel (Japan)	*Trachurus japonicus* (Temminck and Schlegel)
Horse mackerel (California)	*Trachurus symmetricus* (Ayres)
Horse mackerel (Oceania)	See scad (Australia)
Hottentot	*Pachymetopon blochii* (Valenciennes)
Huchen (Danube)	*Salmo* (*Hucho*) *hucho* (Linnaeus)
Humpback salmon	See pink salmon
Inconnu	*Stenodus leucichthys* Güldenstadt
Indian mackerel	*Rastrelliger kanagurta* (Cuvier)

English	Latin
Indian salmon, syn. "dara" or "kuru"	*Polydactylus* (*Polynemus*) *indicus* Shaw
Jack mackerel	*Trachurus trachurus* (Linnaeus)
Jack mackerel (Atlantic)	*Caranx hippos* (Linnaeus)
Jack mackerel (Indian Ocean)	*Caranx sexfasciatus* Quoy and Gaimard
Jack mackerel (Japan)	See horse mackerel (Japan)
Jacopever (South Atlantic)	*Sebastichthys capensis* (Gmelin)
Japanese mackerel	See Pacific mackerel
Japanese salmon	See salmon, cherry
Japanese sea perch	*Lateolabrax japonicus* (Cuvier)
Japanese sole	*Glyptocephalus stelleri* (Schmidt)
Japanese tuna	*Thunnus thynnus orientalis* (Temminck and Schlegel)
Jewfish (India), syn. "ghol"	*Johnius* (*Sciaena*) *sina* (Cuvier)
John Dory (United Kingdom, South Africa)	*Zeus faber* Linnaeus, syn. Z. *Capensis* Cuvier
John Dory (Australia)	*Zeus australis* Richardson
John Dory (Japan)	*Zeus japonicus* Valenciennes
Kabeljou	*Johnius hololepidotus* Lacépède
"Kalankan" (Indonesia)	See turbot (Indo-Pacific)
Kamchatka salmon	*Salmo mykiss* Walbaum
"Killifish" (Japan)	*Oryzias latipes* (Temminck and Schlegel)
King mackerel	*Scomberomorus regalis* (Bloch) and *Sierra cavalla* Cuvier
King salmon	*Oncorhynchus tschawytscha* (Walbaum)
Kingfish (Australian)	See Albacore (Atlantic)
Kingfish (Indian Ocean)	*Caranx* spp.
Kingklip	*Genypterus capensis* Smith
Ladyfish	*Elops saurus* Linnaeus
Lake herring (Lake Michigan)	*Coregonus clupea formis* (Mitchill)
Lake herring (Great Lakes, excluding Lake Michigan)	*Coregonus Leucichthys artedii* LeSueur
Lake sturgeon (United States)	*Acipenser fulvescens* Rafinesque
Lamprey (Atlantic and Great Lakes)	*Petromyzon marinus* Linnaeus
Lamprey (Caspian)	*Caspiomyzon wagneri* Kessler
Lamprey (Northeast Asia)	*Lampetra japonica* (Martens)
Lamprey, river	*Lampetra fluviatilis* and *L. ayresi* (Günther)
Lance	See sand eel
Lancetfish	*Alepisaurus ferox* Lowe
Lantern fish	*Diaphus coeruleus* Klunzinger
Lascar	See sand sole (Europe)
Leather fish, syn. tub, yellow gurnard	*Monacanthus cirrhifer*, syn. *Trigla hirundo* Linnaeus

English	Latin
Lemon sole (Northeast Atlantic)	*Microstomus* (*Pleuronectes*) *microcephalus* (Donovan)
Lemon sole (Oceania)	*Peltotretis flavilatus* Waite
Ling	*Molva* spp.
Ling, common	*Molva molva* (Linnaeus)
Ling, blue	*Molva dipterygia* (Pennant)
Ling (Mediterranean)	*Molva elongata* Risso
Ling (Oceania)	*Genypterus blacodes* Bloch and Schneider and *G. microstomus* Regan
Ling (Canada) (fresh-water)	*Lota maculosa* (LeSueur)
Lingcod	*Ophiodon elongatus* Girard
Little skate	See skate, little
Little tuna (Pacific, Indian Oceans)	*Euthynnus affinis* (Cantor)
Little tuna (Atlantic, Mediterranean)	*Euthynnus alletteratus* (Rafinesque)
Lizardfish	*Chlorophthalmus albatrossis* Jordan and Starks
Loach (minnow)	*Tiaroga cobitis* Girard
Longhorn sculpin	*Myoxocephalus octodecemspinosus* (Mitchill)
Longnose	See lancetfish
Long-nosed skate	See skate, long-nosed
Lumpfish	See lumpsucker
Lumpsucker	*Cyclopterus lumpus* Linnaeus
Maasbanker	South African name for horse mackerel
Mackerel (Atlantic)	*Scomber scombrus* Linnaeus
Mackerel (Oceania)	*Trachurus declivis*
Mackerel (Pacific)	See Pacific mackerel
Mackerel, Atka	*Pleurogrammus azonus* Jordan and Metz, syn. *P. monopterygius* (Pallas)
Mackerel shark	See porbeagle
Mackerel, Spanish	*Scomber maculatus* (Mitchill)
"Magur" (India)	*Clarias batrachus* Bleeker
"Mandeli" (India)	*Coilia dussumieri* Cuvier and Valenciennes
Man-eater	*Carcharodon carcharias* (Linnaeus)
Marlin	See spearfish
Marlin, black or blue	*Makaira nigricans* Lacépède
Marlin, striped	*Makaira audax* (Philippi)
Marlin, white	*Makaira albida* (Poey)
Megrim	*Lepidorhombus whiff-iagonis* (Walbaum)
Menhaden, Atlantic	*Brevoortia tyrannus* (Latrobe)
Menhaden, Gulf, syn. large-scale menhaden	*Brevoortia patronus* Goode
Mexican platyfish	*Platypoecilus maculatus*
Milkfish	*Chanos* spp.
Minnow	*Phoxinus phoxinus* (Linnaeus)

English	Latin
Mock halibut	See Greenland halibut
Monkfish (Northeast Atlantic), syn. anglerfish	*Lophius piscatorius* Linnaeus
Monkfish (Northwest Atlantic), syn. angelfish	*Squatina squatina* (Linnaeus)
Moonfish (Atlantic)	*Vomer setapinnis* (Mitchill)
Moonfish (Pacific)	*Vomer declivifrons* Meek and Hildebrand
Morgan (India)	*Cirrhina orius mrigala* Hamilton Buchanan
Mud carp	*Cirrhina miitorella* (Cuvier and Valenciennes)
"Muksun" (Russia)	*Coregonus muksun* (Pallas)
Mullet	*Mugil* spp.
Mullet, red (Northeast Atlantic)	*Mullus barbatus* Linnaeus
Mullet, red (West Atlantic)	*Mullus auratus* Jordan and Gilbert
"Muroaji" (Japan)	*Decapterus muroadsi* (Temminck and Schlegel)
Muskellunge	*Esox masquinongy* Mitchill
"Nalim" (Russia)	See burbot
"Navaga" (Russia) (Europe)	*Eleginus navaga* (Pallas)
"Navaga" (Russia) (Northwest Pacific)	*Eleginus gracilis* (Tilesius)
"Nelma" (Russia)	*Stenodus leucichthys nelma* (Pallas)
"Nigisu" (Japan)	*Glossanodon* (*Argentina*) *semifasciatus* (Kishinouye)
Norway haddock	See ocean perch
Nurse	See large or small spotted dogfish
Oceanic bonito	See skipjack
Ocean perch (Northeast Atlantic)	*Sebastes marinus* (*marinus*) (Linnaeus)
Ocean perch (Northwest Atlantic)	*Sebastes mentella* (*marinus*) (Travin)
Ocean pout	*Macrozoarces americanus* (Bloch and Schneider)
Oil sardine (India)	*Sardinella longiceps* Valenciennes
"Omul" (Russia)	*Corcyomus autumnalis* Pallas
Opah	*Lampris regius* (Bonnaterre)
Opaleye	*Girella nigricans* (Ayres)
Owl skate	See skate, owl
Pacific cod	*Gadus* (*morhua*) *macrocephalus* Tilesius
Pacific mackerel	*Scomber japonicus* Houttuyn
"Pala" (India)	*Macrura ilisha* (Buchanan Hamilton)
Pampano, common	*Trachinotus carolinus* (Linnaeus)
Pampano (Indo-Pacific)	*Trachinotus blochii* (Lacépède)
Parrot-fish	*Leptoscarus* spp.
Peamouth	*Mylocheilus caurinus* (Richardson)

English	Latin
Pechora herring	*Clupea harengus suworowi* Rafinesque
Pejerrey (Argentina)	*Odonthestes (Basilichthys) bonariensis*
"Pelyad" (Russia)	*Coregonus peled* (Gmelin)
"Peperek" (Indonesia)	See slimy
Perch (Europe, Asia)	*Perca fluviatilis* Linnaeus
Perch (North America)	*Perca flavescens* (Mitchill)
Perch (Japan)	*Lateolabrax japonicus* (Cuvier)
Perch, giant (Australia)	*Lates calcarifer* (Bloch)
Perch, ocean	See redfish
Peto	*Acanthocybium solandri* (Cuvier and Valenciennes)
Petrale sole	*Eopsetta jordani* (Lockington)
Piked dogfish	See dogfish (Atlantic and Pacific)
Pike (northern)	*Esox lucius* Linnaeus
Pike perch (North America)	See walleye
Pike perch (European, also in Caspian)	*Lucioperca lucioperca* (Linnaeus)
Pilchard sardine (W. Europe)	*Clupea (Sardina) pilchardus pilchardus* (Walbaum)
Pilchard (Mediterranean)	*Sardina pilchardus sardina* Walbaum
Pilchard (Japan)	*Sardina melanosticta* (Schlegel)
Pilchard (Northeast Pacific)	*Sardinops (Sardina) caerulea* Girard
Pilchard (Southwest Pacific)	*Sardinops sagax sagax* (Jenyns)
Pilchard (West Africa)	*Sardinella aurita* Cuvier and Valenciennes
Pilchard (South Africa)	*Sardinops ocellata* (Pappe)
Pilchard (Oceania)[*]	*Sardinella neopilchardus* (Steinacher)
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Pintado	*Scomberomorus regalis* (Bloch)
Piranha (Amazon)	*Serrasalmus (Rooseveltiella) nattereri* (Kner)
Pirarucu (Amazon)	*Arapaima gigas* Cuvier
Plaice (Northeast Atlantic)	*Pleuronectes platessa* Linnaeus
Plaice (North America)	See American plaice
Polar cod	*Boreogadus saida* (Lepechin)
Polar plaice	*Liopsetta glacialis* (Pallas)
Pole dab	See witch flounder
Pollock (Europe)	*Pollachius pollachius* (Linnaeus)
Pollock (Alaska)	*Theragra chalcogramma* (Pallas)
Pomfret (United States)	*Brama raii* (Bloch)
Pomfret, black	*Stromateus niger* Bloch
Pomfret, white	*Stromateus cinereus* Bloch
Poor cod	*Gadus minutus* Linnaeus
Pope, syn. ruffe	*Acerina cernua* (Linnaeus)
Porbeagle	*Lamna nasus* (Bonnaterre)
Porgy	*Pagrosomus* spp., *Stenotomus* spp., and *Calamus* spp.

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[*] In smaller sizes most of these pilchards are generally called sardines.

English	Latin
Pout	See bib
Poutassou	*Gadus* (*Micromesistius*) *poutassou* (Risso)
Pouting	See bib
Powan	*Coregonus lavaretus* (Linnaeus)
Puff-fish	See puffers
Puffers	*Sphaeroides* spp.; see also globefish
Rabbitfish	*Chimaera monstrosa* Linnaeus
Rainbow trout (North America)	*Salmo gairdneri* (*irideus*) (Richardson)
Rattail	*Macrourus* spp.
Rays:	*Raja* spp.; see also skates
Shagreen	*R. fullonica* Linnaeus
Thornbock, roughback	*R. clavata* Linnaeus
Spotted, homelyn	*R. montagui* Fowler
Blonde	*R. brachyura* Lafont
Starry	*R. radiata* Donovan
Sandy	*R. circularis* Couch
Painted	*R. microcellata* Montagu
Cuckoo	*R. naevus* Müller and Henle
Undulate, marbled	*R. undulata* Lacépède
Razorbelly	See scaled sardine
Red-eye	See rudd
Red bream (Northeast Atlantic)	See sea bream, common
Red goatfish	See red mullet (Florida)
Red mullet (Florida)	*Mullus auratus* Jordan and Gilbert
Red mullet (Europe)	*Mullus barbatus* (Linnaeus)
(Red) rowan	*Chrysoblephus laticeps* (Cuvier)
Red snapper	*Lutjanus blackfordi* Goode and Bean
Red steenbras	*Dentex* (*Petrus*) *rupestris* (Valenciennes)
Red stumpnose (South Africa)	*Chrysoblephus gibbiceps* Cuvier
Redfish (East Atlantic)	See ocean perch (Northeast Atlantic)
Redfish (West Atlantic)	See ocean perch (Northwest Atlantic)
River lamprey (Europe)	See lamprey, river
River lamprey (Japan)	See lamprey (Northeast Asia)
Roach (Europe)	*Leuciscus* (*Rutilus*) *rutilus* (Linnaeus)
Rock bass	*Ambloplites rupestris* (Rafinesque)
Rockfish, blue (Northeast Pacific)	*Sebastosomus mystinus* (Jordan and Gilbert)
Rockfish, brown (China)	*Sebastodes inermis*
Rockfish (Europe)	See catfish and wolffish
Rockfish (Japan)	*Sebastiscus marmoratus* (Cuvier)
Rockfish, rosy (Northeast Pacific)	*Sebastomus rosaceus* Girard
Rockfish (Northwest Pacific)	*Sebastodes flammeus*

English	Latin
Rock sole	*Lepidopsetta bilineata* (Ayres)
Rock salmon	See dogfish
"Rohu" (India)	*Labeo rohita* Buchanan Hamilton
Roker	See ray
Roughback	See dab, long rough
Round herring (Caribbean)	*Etrumeus sadina* (Mitchill)
Round scad	*Decapterus punctatus* (Agassiz)
Rudd	*Scardinius erythrophthalmus* (Linnaeus)
Russian sturgeon	*Acipenser güldenstädti* Brandt
Sablefish	*Anoplopoma fimbria* (Pallas)
Saffron cod	*Eleginus gracilis* (Tilesius)
Sailfin	See sandfish (Japan)
Sailfish	*Istiophorus* spp.
Sailfluke	See megrim
Saithe	See coalfish
Salmon (Atlantic); see also huchen	*Salmo salar* Linnaeus
Salmon (Australia)	*Arripis trutta* Bloch and Schneider
Salmon (Pacific), syn. Chum salmon or dog salmon	*Oncorhynchus keta* (Walbaum)
Salmon (Pacific), syn. sockeye (red)	*Oncorhynchus nerka* (Walbaum)
Salmon, cherry	*Oncorhynchus masou* (Brevoort)
Salmon, king or chinook	*Oncorhynchus tschawytscha* (Walbaum)
Salmon, pink, syn. humpback salmon	*Oncorhynchus gorbuscha* (Walbaum)
Salmon, sebago	*Salmo sebago* Girard
Salmon, silver, syn. Coho salmon or silversides	*Oncorhynchus kisutch* (Walbaum)
Salmon bass (Australia)	See kabeljou
Salmon bass (Atlantic)	See bass (Atlantic)
Salmon shark	*Lamna nasus* (Bonnaterre)
Sand eel	See sand launce (Northeast Atlantic)
Sandfish (Japan)	*Arctoscopus japonicus* (Steindachner)
Sand launce (Northeast Atlantic)	*Ammodytes* spp. and *Gymnammodytes* spp.
Sand sole (flounder) (Pacific)	*Psettichthys melanostictus* Girard
Sand sole (Europe)	*Solea lascaris* (Risso)
Sardine (Northeast Altantic)	*Clupea* (*Sardina*) *pilchardus pilchardus* (Walbaum)
Sardine (Australia)	*Sardina* (*Sardinops*) *neopilchardus* (Steinacher)
Sardine (Northeast Pacific)	*Sardinops* (*Sardina*) *caerulea* Girard
Sardine (Southwest Pacific)	*Sardinops sagax sagax* (Jenyns) (by some ichthyologists considered identical to the North Pacific species)

English	Latin
Sardine (Maine)	*Clupea harengus* Linnaeus
Sardine (India)	*Sardinella fimbriata* (Valenciennes)
Sardine (Northwest Pacific)	*Sardina (Sardinops) melanosticta* (Temminck and Schlegel)
Sardine (Scandinavia), syn. brisling	*Clupea sprattus* (Linnaeus)
Sardine (South Africa)	*Sardina ocellata* Jenyns
Sauger	*Stizostedion canadens* (Smith)
Saurel	See horse mackerel (Atlantic)
Saury (Pacific)	*Cololabis saira* (Brevoort) and *C. brevirostris* (Peters)
Saury pike (Atlantic), syn. skipper	*Scomberesox saurus* (Walbaum)
Scabbardfish (Northeast Atlantic)	*Lepidopus caudatus* (Euphrasen)
Scabbardfish (Northwest Atlantic)	*Trichiurus lepturus* Linnaeus
Scad (Northeast Atlantic)	See jack mackerel
Scad (Australian), syn. horse mackerel (Oceania)	*Trachurus novae-zelandiae* Richardson
Scaldfish	*Arnoglossus laterna* (Walbaum)
Scaled sardine	*Harengula pensacolae* Goode and Bean
Scup	*Stenotomus versicolor* (Mitchill)
Sea bass (Japan)	*Lateolabrax japonicus* (Cuvier)
Sea bass, white (California)	*Atractoscion nobilis* (Ayres)
Sea bream (Northwest Atlantic)	*Brama* spp. and *Taractes princeps* (Johnson)
Sea bream, common	*Pagellus centrodontus* (de la Roche)
Sea bream	Various species of the family Sparidae (including red bream above)
Sea lamprey	See lamprey
Sea perch, syn. white perch	*Morone americanus* (Gmelin)
Sea pike (Australia)	See snook (Australia)
Sea raven	*Hemitripterus americanus* (Gmelin)
Sea robin	*Prionotus* spp. and *Peristedion* spp.
Sea trout	*Salmo trutta trutta* Linnaeus
Sebago salmon	*Salmo sebago* Girard
"Sevruga" (Russia)	*Acipenser stellatus* Pallas
Shad (American)	*Alosa sapidissima* Wilson
Shad, Allis	See alewife
Shad, gizzard	*Dorosoma cepedianum* (LeSueur)
Shad, Twaite	*Clupea finta* (Cuvier)
Shark, basking	*Cetorhinus maximus* (Gunnerus)
Shark, great blue	*Prionace glauca* (Linnaeus)
Shark, Greenland	*Somniosus microcephalus* (Bloch and Schneider)
Shark, hammerhead (smooth)	*Sphyrna zygaena* Linnaeus

English	Latin
Shark, salmon	*Lamna nasus* (Bonnaterre)
Shark, silver	*Chimaera monstrosa* Linnaeus
Shark, soupfin	*Galeorhinus zyopterus* (Jordan and Gilbert)
Shark, tiger	*Galeocerdo cuvieri* (Peron and LeSueur)
Shark, white	See man-eater
Sharp-nosed skate	See skate, sharp-nosed
Sheatfish	*Siluris glanis* (Linnaeus)
Sheepshead (marine)	*Archosargus probatocephalus* (Walbaum)
"Shirada" (India)	*Wallago attu* Bleeker
Shovelnose sturgeon	*Scaphirhynchus platorhynchus* Rafinesque
Siberian cisco	*Coregonus sardinella* Valenciennes
Sierra	See King mackerel
Silverbelly (India)	*Leiognathus* (*Equula*) *bindus* Cuvier and Valenciennes
Silver carp	*Hypothalmichthys molitrix* Valenciennes
Silver salmon	*Oncorhynchus kisutch* (Walbaum)
Silversides	See salmon, silver
Silver hake	See whiting (Northwest Atlantic)
Silver perch	See drum (fresh-water)
Silver salmon	See salmon, silver
Skates:	*Raja* spp.; see also rays
Skate	*R. batis* Linnaeus
Little	*R. erinacea* Mitchill
Long-nosed	*R. oxyrhynchus* Linnaeus
Owl	*R. marginata* Lacépède
Sharp-nosed	*R. lintea* Fries
Skipjack	*Euthynnus* (*Katsuwonus*) *pelamis* (Linnaeus)
Skipper	See saury pike
Slimy	*Leiognathus equula* Forskal
Small-mouth buffalo	*Ictiobus bubalus* Rafinesque
Smelt (Europe)	*Osmerus eperlanus* (Linnaeus)
Smelt (Columbia River)	See eulachon
Smelt (Northwest Atlantic and Lake Michigan)	*Osmerus mordax* (Mitchill)
Smelt, pond	*Hypomesus olidus* (Pallas)
Smooth-hound	See dogfish, smooth
Snapper	*Lutjanus* spp.
Snoek (South Africa)	*Thyrsites atun* (Euphrasen)
Snook (Oceania)	*Australuzza novae-hollandiae* Günther
Soapy	See slimy
Sockeye (red) salmon	*Oncorhynchus nerka* (Walbaum)
Sole (East Pacific)	See rock sole
Sole (Europe)	*Solea vulgaris* (Day), syn. *Solea solea* (Linnaeus)
Sole (India)	*Cynoglossus semifasciatus*
Sole, lemon	See lemon sole
"Som" (Russia)	See sheatfish

English	Latin
Soupfin shark	*Galeorhinus zyopterus* (Jordan and Gilbert)
Spanish mackerel	*Scomberomorus maculatus* (Mitchill)
Sparling	See smelt
Spearfish	*Makaira* spp.
Speckled trout	See brook trout
Spotted catfish	See spotted wolf-fish
Spotted wolf-fish	*Anarhichas minor* Olafsen
Sprat (Europe)	*Clupea sprattus* (Linnaeus)
Sprat (New Zealand)	*Maugeclupea antipodum* (Hector)
Spurdog	See dogfish
Squirrel hake	*Urophycis chuss* (Walbaum)
Starry flounder (Pacific)	*Platichthys stellatus* Pallas, syn. *Paralichthys olivaceus* (Temminck and Schlegel)
Steelhead trout	See rainbow trout (North America)
Sterlet (Volga, Danube), "Sterljad" (Russian)	*Acipenser ruthenus* Linnaeus
Stingfish	See great weever
Stingray	*Dasyatis* spp.
Stockfish (South Africa)	*Merluccius capensis* Castlenau
Stone bass	*Polyprion americanus* (Bloch and Schneider)
Striped mullet	*Mugil cephalus* Linnaeus
Striped tuna	See skipjack
Sturgeon	*Acipenser sturio* Linnaeus
Sturgeon, Russian	*Acipenser güldenstädti* Brandt
Sturgeon (Danube), "beluga" (Russian)	*Huso huso* (Linnaeus)
Sturgeon (Caspian) "sevruga" (Russia)	*Acipenser stellatus* Pallas
Sturgeon, lake	*Acipenser fulvescens* Rafinesque
Sturgeon, shovelnose	*Scaphirhynchus platorhynchus* Rafinesque
Sturgeon, white	*Acipenser transmontanus* (Richardson)
Summer flounder	*Paralichthys dentatus* (Linnaeus)
Sunfish (West Atlantic)	*Lepomis* spp.
Sunfish, ocean (Europe)	*Mola mola* Linnaeus
Swordfish	*Xiphias gladius* Linnaeus
"Syrok" (Russia)	See "pelyad"
"Tarshiki" (Japan)	*Cheilodactylus macropterus*
Tench	*Tinca tinca* (Linnaeus)
Thickback	*Solea (Microchirus) variegata* (Donovan)
Thread herring	*Opisthonema oglinum* (LeSueur)
Thresher	*Alopias vulpinus* (Bonnaterre)
Tiger shark	*Galeocerdo cuvieri* (Peron and LeSueur)
Tomcod	*Microgadus tomcod* (Walbaum)
Torsk	See tusk
Tope (Atlantic)	*Galeorhinus galeus* (Linnaeus)

English	Latin
Tope (Oceania)	*Notogaleus rhinophanes* (Peron)
Torpedo	See electric ray
Trout, brook (North America)	*Salvelinus fontinalis* (Mitchill)
Trout (Australia)	*Galaxiids*
Trout, brown	*Salmo trutta* (*fario*) Linnaeus
Trout, cutthroat	*Salmo clarki* (Richardson)
Trout (Japanese) (marine)	See cherry salmon
Trout, lake (North America)	*Salvelinus* (*Cristivomer*) *namaycush* (Walbaum)
Trout, rainbow (North America)	*Salmo gairdneri irideus* Richardson
Trout, spotted sea (North America)	*Eriscion nebulosus* Cuvier and Valenciennes
Trout, sea (North America)	*Cynoscion regalis* (Bloch and Schneider)
Tuna (Red Sea)	*Gymosarda unicolor* (Rüppell)
Tunny	See bluefin tuna
Turbot (North Atlantic)	*Rhombus* (*Scopthalmus*) *maximus* (Linnaeus)
Turbot (Indo-Pacific, Australia)	*Psettodes erumei* (Schneider)
Turbot (North Pacific)	See arrow-toothed flounder
Tusk	*Brosme brosme* (Müller)
Twaite shad	*Clupea finta* (Cuvier)
Vendace	*Coregonus albula* (Linnaeus)
Vimba (Baltic, Mediterranean, Caspian)	*Vimba vimba* (Linnaeus)
"Vobla" (Russia)	See Caspian roach
"Wahoo"	See peto
Walleye (pike), blue	*Stizostedion vitreum glaucum* (Hubbs)
Walleye (pike)	*Stizostedion vitreum vitreum* (Mitchill)
Whiff	See megrim
Whitebait (Europe and North America)	*Clupea sprattus* or other small-sized *Clupea*
Whitefish, common	*Coregonus clupeaformis* (Mitchill)
Whitefluke	See flounder (Europe)
White amur	See grass carp
White bass	*Lepibema chrysops* Rafinesque
White-bellied skate	See skate, owl
White hake	*Urophycis tenuis* (Mitchill)
White perch (fresh-water)	See drum (fresh-water)
White perch (marine)	See sea perch
White sea bass (California)	*Cynoscion nobilis* Ayres
White shark	See man-eater
White sole (Europe)	See witch flounder
White steenbras	*Lithognathus lithognatus* (Cuvier)
White stumpnose (South Africa)	*Rhabdosargus globiceps* (Cuvier)

English	Latin
White sturgeon	*Acipenser transmontanus* (Richardson)
Whiting (Australia)	*Sillago* spp.
Whiting (Europe)	*Gadus* (*Odontogadus*) *merlangus* (Linnaeus)
Whiting (Northwest Atlantic)	*Merluccius bilinearis* (Mitchill)
Whiting, big-eye (Pacific)	See Alaska pollock
Winter carp	See bigmouth
Winter flounder	*Pseudopleuronectes americanus* (Walbaum)
Witch flounder	*Glyptocephalus cynoglossus* Linnaeus
Wolf-fish (Atlantic)	*Anarhicas lupus* Linnaeus
Wrasse (Europe)	Various species of Labridae
Wreckfish	See stone bass
Yellow bullhead	*Ictalurus natalis* (LeSueur)
Yellow pike	See walleye
Yellowfin (tuna)	*Thunnus albacora* (Lowe), syn. *Neothunnus macropterus*
Yellowfin sole	*Limanda aspera* (Pallas)
Yellowtail (Atlantic)	*Seriola lalandi* Valenciennes
Yellowtail (Australia)	*Trachurus declivis*
Yellowtail flounder (Northwest Atlantic)	*Limanda ferruginea* (Storer)

Latin	English
Abramis brama (Linnaeus)	Bream (fresh-water)
Acanthias vulgaris	See *Squalus acanthias*
Acanthocybium solandri (Cuvier and Valenciennes)	Peto, syn. "wahoo"
Acanthopagrus australis (Günther)	Black bream (Australia)
Acerina cernua (Linnaeus)	Pope, syn. ruffe
Acipenser fulvescens Rafinesque	Lake sturgeon
Acipenser güldenstädti Brandt	Russian sturgeon
Acipenser medirostris Ayres	Sakhalin sturgeon
Acipenser ruthenus Linnaeus	Sterlet (Volga, Danube) (Russian "sterljad")
Acipenser stellatus Pallas	"Sevruga" (Russian), syn. Caspian sturgeon
Acipenser sturio Linnaeus	Sturgeon, syn. Baltic sturgeon
Acipenser transmontanus (Richardson)	White sturgeon
Aldrichetta forsteri Cuvier and Valenciennes	Herring (Oceania)
Alepisaurus ferox Lowe	Lancetfish, syn. longnose
Alopias vulpinus (Bonnaterre)	Thresher

Latin	English
Alosa sapidissima Wilson	American shad
Ambloplites rupestris (Rafinesque)	Rock bass
Ammodytes spp.	Sand launce; see also *Gymnammodytes* spp.
Anarhichas lupus Linnaeus	Atlantic wolf-fish, syn. catfish
Anarhichas minor Olafsen	Spotted catfish, syn. spotted wolf-fish
Anchoviella indica van Hasselt, syn. *Engraulis* (*Stolephorus*) *indicus*	Anchovy (India)
Anguilla anguilla Linnaeus	Eel (European)
Anguilla aucklandii Philippi	Eel (Australia)
Anguilla japonica Temminck and Schlegel	Eel (Japanese)
Anguilla rostrata LeSueur	Eel (American)
Anoplopoma fimbria (Pallas)	Sablefish
Aorhamphus spp.	Garfish, sea (Australia)
Aplodinotus grunniens (Rafinesque)	Fresh-water drum
Arapaima gigas Cuvier	Pirarucu (South America)
Archosargus probatocephalus (Walbaum)	Sheepshead (marine)
Arctoscopus japonicus (Steindachner)	Sandfish
Argentina semifasciata Kishinouye	"Nigisu" (Japan)
Argentina sialis Gilbert	Argentine (Pacific)
Argentina silus Ascanius	Argentine (Atlantic)
Aristichthys nobilis (Richardson)	Bighead
Arnoglossus laterna (Walbaum)	Scaldfish
Arripis trutta Bloch and Schneider	Salmon (Australia), kahawai
Astroconger myriaster (Brevoort)	Conger eel (Northwest Pacific)
Atheresthes stomias (Jordan and Gilbert)	Arrow-toothed flounder (halibut)
Atractoscion aequidens Cuvier	Geelbek, syn. Cape salmon
Atractoscion nobilis (Ayres)	White sea bass (California)
Australuzza novae-hollandiae Günther	Snook (Oceania), syn. sea pike
Auxis thazard (Lacépède)	Frigate mackerel
Barbus barbus (Linnaeus)	Barbel
Belone belone Linnaeus	Gar pike, syn. garfish
Beryx splendens Lowe	Alfonsino
Boreogadus saida (Lepechin)	Polar (Arctic) cod, syn. "saika" (Russia)
Brama spp.	Sea bream (Northwest Atlantic); see also *Taractes princeps* (Johnson)
Brama raii (Bloch)	Pomfret (United States)
Branchiostegus japonicus (Houttuyn) and others	Blanquillo
Brevoortia patronus Goode	Gulf menhaden
Brevoortia tyrannus (Latrobe)	Menhaden (Atlantic)
Brosme brosme (Müller)	Cusk, syn. torsk, tusk

Latin	English
Calamus spp.	Porgies
Callorhynchus milii Bory de St. Vincent, syn. *Mormyrus petersi*	Elephant fish
Caranx bartholomaei (Cuvier)	Jack, see also *C. crysos* Mitchill
Caranx crysos (Mitchill)	Jack, see also *C. bartholomaei* (Cuvier)
Caranx hippos (Linnaeus)	Jack (Atlantic), syn. crevalle jack, and jack
Caranx sexfasciatus Quoy and Gaimard	Jack (Indian Ocean), syn. crevalle, kingfish
Caranx (*Trachurus*) *tracurus* (Linnaeus)	Horse mackerel, syn. saurel, maasbanker, scad, capefish, jack mackerel
Carassius auratus Linnaeus	Goldfish
Carassius carassius (Linnaeus)	Crucian carp, syn. German (or Prussian) carp
Carcharodon carcharias (Linnaeus)	Man-eater, syn. white shark
Caspiomyzon wagneri (Kessler)	Caspian lamprey
Cetorhinus maximus (Gunnerus)	Basking shark, syn. herring hog
Chanos spp.	Milkfish
Cheilodactylus macropterus	"Tarshiki" (Japan)
Chelidonichthys (*Trigla*) *kumu* Lesson and Garnot	Gurnard, red (Japan)
Chimaera monstrosa Linnaeus	Rabbitfish, syn. king of the herrings, silver shark
Chlorophthalmus albatrossis Jordan and Starks	Lizardfish
Chrysoblephus gibbiceps Cuvier	Red stumpnose (South Africa)
Chrysoblephus laticeps Cuvier	(Red) rowan (South Africa)
Chrysophris auratus (Bloch and Schneider)	Gilthead
Cirrhina orius mrigala Hamilton Buchanan	Morgan (India)
Cirrhina miitorella (Cuvier and Valenciennes)	Mud carp
Clarias batrachus Bleeker	"Magar" (India)
Clupanodon punctatus	Thread herring
Clupea (*Alosa*) *alosa* Linnaeus	Alewife (Europe), syn. Allis shad, shad, rock herring
Clupea finta (Cuvier)	Twaite shad
Clupea harengus Linnaeus	Herring (Atlantic), Maine sardine
Clupea harengus pallasi (Cuvier and Valenciennes)	Herring (Pacific)
Clupea harengus suworowi Rafinesque	Pechora herring
Clupea (*Sardina*) *pilchardus pilchardus* (Walbaum)	Pilchard sardine (Northwest Atlantic)
Clupea sprattus (Linnaeus)	Sprat (Europe), syn. sardine or brisling (Scandinavia), whitebait (Europe and North America)
Coilia dussumieri Cuvier and Valenciennes	"Mandeli" (India)

Latin	English
Colistium güntheri (Hutton)	Brill (Oceania)
Cololabis brevirostris (Peters)	Pacific saury; see also *C. saira* (Brevoort)
Cololabis saira (Brevoort)	Pacific saury; see also *C. brevirostris* (Peters)
Conger conger (Linnaeus)	Conger eel (Northeast Atlantic)
Conger oceanicus (Mitchill)	Conger eel (Northwest Atlantic)
Coregonus albula (Linnaeus)	Vendace
Coregonus (*Leucichthys*) *artedii* (LeSueur)	Cisco
Coregonus autumnalis (Pallas)	Arctic cisco, syn. "Omul" (Russian)
Coregonus clupeaformis (Mitchill)	Whitebait (Australia), syn. lake herring (Lake Michigan), or common whitefish
Coregonus lavaretus (Linnaeus)	Powan, syn. "sig" (Russia), "sik" (Scandinavian)
Coregonus muksun (Pallas)	"Muksun" (Russia)
Coregonus nasus (Pallas)	Broad whitefish
Coregonus oxyrhynchus Linnaeus	Houting (Scandinavian lakes, Baltic, North Sea)
Coregonus peled (Gmelin)	"Pelyad" (Russia) or "syrok" (Russia)
Coregonus sardinella Valenciennes	Siberian cisco, syn. least cisco
Coryphaena hippurus Linnaeus	Dolphin, syn. dorado
Cristivomer namaycush, syn. *Salvelinus namaycush* (Walbaum)	Char (Great Lakes), lake trout
Ctenopharyngodon idella (Cuvier and Valenciennes)	Grass carp, syn. white amur (Russia)
Cyclopterus lumpus Linnaeus	Lumpsucker, syn. lumpfish
Cynoglossus semifasciatus Day	Sole (India)
Cynoscion regalis (Bloch and Schneider)	Weakfish, syn. sea trout (North America)
Cynoscion nobilis (Ayres)	White sea bass (California)
Cyprinus carpio (Linnaeus)	Common carp
Cypselurus spp.	Flying fishes
Dasyatis spp.	Stingray
Decapterus punctatus (Agassiz)	Round scad, syn. cigarfish
Decapterus muroadsi (Temminck and Schlegel)	"Muroaji" (Japan)
Dentex (*Petrus*) *rupestris* (Valenciennes)	Red steenbras
Diaphus coeruleus Klunzinger	Lantern fish
Dorosoma cepedianum (LeSueur)	Gizzard shad

Latin	English
Eleginus gracilis (Tilesius)	Saffron cod, syn. Far East "navaga"
Eleginus navaga (Pallas)	"Navaga" (Russia)
Elops saurus Linnaeus	Cape salmon, syn. ladyfish
Emissola antarctica (Günther)	Smoothhound (dogfish), syn. "manga"
Enedrias nebulosus (Temminck and Schlegel)	Blenny
Engraulis (*Stolephorus*) *indicus*	See *Anchoviella indica*
Engraulis japonicus (Houttuyn)	Anchovy (Japan)
Engraulis mordax (Girard)	Anchovy, northern (East Pacific)
Engraulis pseudoharengus Wilson, syn. *E. encrasicholus* Linnaeus	Anchovy (Europe)
Entosphenus japonicus Martens	See *Lampetra japonica*
Eopsetta jordani (Lockington)	Petrale sole
Epinephelus spp.	Grouper (Atlantic)
Erilepis zonifir Linnaeus	Black cod
Eriscion nebulosus Cuvier and Valenciennes	Spotted sea trout
Esox lucius (Linnaeus)	Northern pike
Esox masquinongy Mitchill	Muskellunge
Esox niger LeSueur	Chain pickerel
Etrumeus micropus (Schlegel)	Round herring, syn. herring (Indo-Pacific)
Etrumeus sadina (Mitchill)	Herring (Caribbean), syn. Atlantic round herring
Eumakaira negra (Nakamura), syn. *Makaira nigricans marlina* (Lacépède)	Black marlin
Euthynnus affinis (Cantor)	Little tuna (Pacific and Indian Oceans)
Euthynnus alletteratus (Rafinesque)	Little tuna (Atlantic, Mediterranean)
Euthynnus (*Katsuwonus*) *pelamis* (Linnaeus)	Skipjack, syn. oceanic bonito
Gadus callarias (Linnaeus), syn. *Gadus morhua* Linnaeus	Cod (Atlantic), codling
Gadus luscus Linnaeus	Bib, syn. pout, pouting
Gadus (*morhua*) *macrocephalus* (Tilesius)	Pacific cod, syn. gray cod
Gadus (*Odontogadus*) *merlangus* (Linnaeus)	Whiting (Europe)
Gadus minutus Linnaeus	Poor cod
Gadus ogac Richardson	Greenland cod
Gadus (*Micromesistius*) *poutassou* (Risso)	Poutassou, syn. blue whiting
Galaxias spp.	Trout (Australia)
Galeocerdo cuvieri (Peron and LeSueur)	Tiger shark
Galeorhinus australis	Shark (Oceania)
Galeorhinus galeus (Linnaeus)	Tope (Atlantic)

Latin	English
Galeorhinus zyopterus (Jordan and Gilbert)	Soupfin shark
Galeus vulgaris (Fleming)	Tope (Atlantic)
Genypterus blacodes Bloch and Schneider	Ling (Oceania)
Genypterus capensis Smith	Kingklip, syn. koningklip
Genypterus microstommus Regan	Ling (Oceania)
Girardinus guppyi Günther	Guppy
Girella tricuspidata	Blackfish (Australia)
Girella nigricans (Ayres)	Opaleye
Girella punctata Gray	Greenfish
Glossanodon (*Argentina*) *semifasciatus* (Kishinouye)	"Nigisu" (Japan)
Glossogobius (*Gobius*) *giuris* Hamilton Buchanan	"Bele" or "gula" (India)
Glyptocephalus cynoglossus Linnaeus	Witch flounder (United States), syn. white sole (Europe), pole dab (Europe)
Glyptocephalus stelleri (Schmidt)	Japanese sole
Gymnammodytes spp.	Sand launce; see also *Ammodytes spp.*
Gymnosarda nuda	Dogtooth tuna (Red Sea)
Harengula pensacolae Goode and Bean	Scaled sardine, syn. razorbelly
Harpodon nehereus Günther	Bombay duck, syn. "bombil" (India)
Helioperca incisor Cuvier and Valenciennes	See *Lepomis macrochirus* Rafinesque
Hemirhamphus spp.	Garfish, sea (Australia)
Hemitripterus americanus (Gmelin)	Sea raven
Hexea (*Rexea*) *solandri* (Cuvier)	Hake (Australia)
Hilsa ilisha Regan	See *Macrurus ilisha* (Buchanan Hamilton)
Hippoglossoides classodon Jordan and Gilbert	Flathead sole
Hippoglossoides platessoides (Fabricius)	American plaice
Hippoglossus stenolepis (Schmidt)	Halibut (Pacific)
Hippoglossus hippoglossus, syn. *H. vulgaris* Linnaeus	Halibut (Atlantic)
Hirundichthys affinis (Günther)	Flying fish
Holocanthus spp.	Angelfish (United States); see also *Pomocanthus* spp.
Hucho hucho (Linnaeus)	Huchen, syn. Danube salmon
Hucho taimen (Pallas)	Amur salmon, also in Upper Volga and the Pechora River.
Huso huso (Linnaeus)	"Beluga," syn. great white sturgeon, sturgeon (Danube)
Hypomesus olidus (Pallas)	Pond smelt
Hyporhamphus spp.	Garfish, sea (Australia)
Hypothalmichthys molitrix Valenciennes	Silver carp

Latin	English
Ictalurus spp.	Bullhead or catfish (freshwater)
Ictalurus natalis (LeSueur)	Yellow bullhead
Ictiobus bubalus Rafinesque	Smallmouth buffalo
Ictiobus cyprinellus (Valenciennes) or other *I.* species	Buffalofish, syn. bigmouth or winter carp
Istiophorus spp.	Sailfish
Isopsetta isolepis (Lockington)	Butter sole
Johnius hololepidotus Lacépède	Kabeljou (South Africa)
Johnius (*Sciaena*) *sina* (Cuvier)	Jewfish (India), syn. "ghol"
Katsuwonus pelamis (Linnaeus)	See *Euthynnus pelamis* (Linnaeus)
Labeo rohita Buchanan Hamilton	"Rohu" (India)
Labrax lupus	See *Morone labrax Linnaeus*
Labridae, various species	Wrasse (Europe)
Lagodon rhomboides (Linnaeus)	Sailors-choice
Lamna nasus (Bonnaterre)	Porbeagle, syn. mackerel shark, salmon shark
Lampetra ayresii (Günther)	River lamprey
Lampetra fluviatilis (Linnaeus)	River lamprey, see also *L. ayresii*
Lampetra japonica (Martens)	Japanese lamprey
Lampris regius (Bonnaterre)	Opah
Lateolabrax japonicus (Cuvier)	Sea perch (Japan), syn. sea bass
Lates calcarifer Günther	Giant perch (Australia), syn. barragmundi
Leiognathus (*Equula*) *bindus* (Cuvier and Valenciennes)	Silverbelly (India)
Leiognathus equula Forskål	Slimy, syn. soapy
Lepibema chrysops Rafinesque	White bass
Lepidopsetta bilineata (Ayres)	Rock sole
Lepidopus caudatus (Euphrasen)	Scabbardfish (Northeast Atlantic)
Lepidorhombus whiff-iagonis (Walbaum)	Megrim, syn. whiff, sailfluke
Lepidotrigla microptera Günther	Gurnard (Japan), sea robin; see also *Chelidonichthys kumu*
Lepomis spp.	Sunfish (West Atlantic), syn. "peperek" (Indonesia)
Lepomis macrochirus Rafinesque	Bluegill
Leptoscarus spp.	Parrot fish

Latin	English
Leuciscus idus Linnaeus	Ide, syn. "yaz" (Russia)
Leuciscus (*Rutilus*) *rutilus* (Linnaeus)	Roach (Europe)
Leucichthys spp.	Chub (North America)
Limanda aspera (Pallas)	Yellowfin sole
Limanda ferruginea (Storer)	Yellowtail flounder (Northwest Atlantic)
Limanda limanda (Linnaeus)	Dab (Europe)
Limanda yokohamae, syn. *Paralichthys olivaceus* (Temminck and Schlegel)	Flatfish (Japan), syn. "hirame"
Liopsetta exilis (Jordan and Gilbert)	Slender sole (Northeast Pacific)
Liopsetta glacialis (Pallas)	Polar plaice, syn. Arctic flounder
Liopsetta putnami (Gill)	Small mouth flounder (Canada)
Lithognathus lithognathus Cuvier	White Steenbras, syn. whitefish (South Africa)
Lophius americanus Valenciennes	Angler (Northwest Atlantic), syn. goosefish
Lophius litulon Jordan	Angler (Japanese)
Lophius piscatorius Linnaeus	Anglerfish, syn. monkfish, fishing frog, or silver salmon
Lophopsetta maculata (Mitchill)	Brill (Northwest Atlantic)
Lota lota (lacustris) (Walbaum), syn. *Lota vulgaris*	Burbot, syn. "nalim" (Russia)
Lota maculosa (LeSueur)	Ling (Canada) (fresh-water)
Lucioperca lucioperca (Linnaeus)	Pike-perch (Europe)
Lutjanus blackfordi Goode and Bean	Red snapper
Macrourus spp.	Rattail, syn. grenadier
Macrozoarces americanus (Bloch and Schneider)	Ocean pout, syn. eelpout
Macrura ilisha (Buchanan Hamilton), syn. *Hilsa ilisha* Reagan	Indian shad, syn. "pala" (India)
Makaira albida (Poey)	White marlin
Makaira ampla (Poey)	Black marlin
Makaira audax (Philippi)	Striped marlin
Makaira nigricans Lacépède	Blue marlin
Mallotus catervarius (Pennant)	Capelin (Arctic)
Mallotus socialis (Pallas)	Capelin (Pacific)
Mallotus villosus (Müller)	Capelin (Atlantic)
Marlina marlina Linnaeus	White marlin, syn. *Makaira albida* (Poey)
Maugeclupea antipodum (Hector)	Sprat (New Zealand)
Megastomatobus cyprinella (Cuvier and Valenciennes)	Bigmouth, syn. buffalofish, winter carp
Melanogrammus (*Gadus*) *aeglefinus* Linnaeus	Haddock (Atlantic)
Merluccius bilinearis (Mitchill)	Whiting (Northwest Atlantic)

Latin	English
Merluccius capensis Castlenau	Stockfish (South Africa), syn. hake (South Africa)
Merluccius gayi Guich	English hake (Oceania)
Merluccius merluccius Linnaeus	Hake (Atlantic)
Merluccius productus Ayres	Hake (Pacific)
Microchirus variegata (Donovan)	See *Solea variegata* (Donovan)
Microgadus tomcod (Walbaum)	Tomcod
Micropogon undulatus (Linnaeus)	Croaker (Atlantic)
Micropterus dolomieu Lacépède	Smallmouth bass
Microstomus (Pleuronectes) microcephalus (Donovan)	Lemon sole (Northeast Atlantic)
Microstomus pacificus (Lockington)	Dover slime sole, syn. Dover sole (Northeast Pacific)
Microstomus stelleri	See *Glyptocephalus stelleri* (Schmidt)
Mola mola Linnaeus	Ocean sunfish (Europe)
Molva dipterygia (Pennant)	Blue ling
Molva elongata Risso	Ling (Mediterranean)
Molva molva (Linnaeus)	Common ling
Molva spp.	Ling
Monacanthus cirrhifer Temminck and Schlegel	Leatherfish, file-fish
Mormyrus oxyrhynchus	Elephantfish (Nile)
Morone americanus (Gmelin)	White perch, syn. sea perch
Morone labrax (Linnaeus), syn. *Labrax lupus*	Bass, syn. salmon bass
Mugil speigleri Bleeker	Mullet (India), syn. "boya"
Mugil cephalus Linnaeus	Striped mullet
Mugil spp.	Mullet (in general)
Mullus auratus Jordan and Gilbert	Red mullet (West Atlantic)
Mullus surmulletus Linnaeus	Red mullet (Europe)
Mustelus canis (Mitchill)	Smooth dogfish (Northwest Atlantic)
Mustelus mustelus Linnaeus	Smooth dogfish, (Northeast Atlantic)
Mylocheilus caurinus (Richardson)	Peamouth
Mylopharyngodon piceus (Richardson)	Blackamur
Myoxocephalus octodecemspinosus (Mitchill)	Longhorn sculpin
Neothunnus macropterus Temminck and Schlegel	Yellowfin (tuna)
Niphon spinosus Cuvier	Common bass (Japan)
Notogaleus rhinophanes (Peron)	Tope (Oceania)
Odonthestes (Basilichthys) bonariensis (Cuvier and Valenciennes)	Pejerrey (Argentina); (in Brazil: peixe-rei)

Latin	English
Odontogadus merlangus (Nordm.)	See *Gadus merlangus* (Linnaeus)
Oncorhynchus gorbuscha (Walbaum)	Pink salmon, syn. humpback salmon
Oncorhynchus keta (Walbaum)	Chum salmon, syn. dog salmon
Oncorhynchus kisutch (Walbaum)	Silver salmon, syn. jack salmon, coho salmon, or silversides
Oncorhynchus masou (Brevoort)	Cherry salmon, syn. Japanese salmon (trout)
Oncorhynchus nerka (Walbaum)	Sockeye (red) salmon
Onchorhynchus tschawytscha (Walbaum)	King salmon, syn. Chinook salmon, black salmon, or chub salmon (spring type)
Ophiocephalus spp.	Blackfish, syn. "maral" (India)
Ophiodon elongatus (Girard)	Ling cod, syn. greenling
Opisthonema oglinum (LeSueur)	Thread herring
Orcynopsis unicolor (St. Hilaire)	Plain bonito
Oryzias latipes (Temminck and Schlegel)	"Killifish" (Japan)
Osmerus eperlanus (Linnaeus)	Smelt, syn. sparling
Osmerus mordax (Mitchill)	Smelt (Northwest Atlantic and Lake Michigan)
Pachymetopon blochii (Valenciennes)	Hottentot
Pagellus centrodontus (de la Roche)	Common sea bream, syn. red bream (Northeast Atlantic)
Pagellus erythrinus (Linnaeus)	Pagel, pagello (Portugal and Italy)
Pagellus lithognathus	See *Lithognathus lithognathus* (Cuvier)
Pagrosomus spp.	Porgy, syn. sea bream
Paralichthys dentatus (Linnaeus)	Summer flounder
Paralichthys olivaceus (Temminck and Schlegel)	"Hirami" (Japan), syn. to *Platichthys stellatus* (Pallas)
Parathunnus sibi (Temminck and Schlegel)	syn. *Thynnus obesus* Lowe
Parophrys vetulus (Girard)	English sole (Northeast Pacific)
Peltotretis flavilatus Waite	Lemon sole (Oceania)
Peltorhamphus novae-zeelandiae Günther	English sole (Oceania), syn. New Zealand common sole
Perca flavescens (Mitchill)	Perch (North America), syn. yellow perch
Perca fluviatilis Linnaeus	Perch (Europe, Asia), syn. lake or river perch
Peristedion spp.	Sea robin; see also *Prionotus* spp.
Petromyzon fluviatilis Linnaeus	See *Lampetra fluviatilis*

Latin	English
Petromyzon marinus Linnaeus	Sea lamprey (Atlantic and Great Lakes)
Petrus rupestris (Valenciennes)	Red steenbras
Phoxinus phoxinus (Linnaeus)	Minnow
Phycis (*Urophycis*) *blennoides* Brünnich	Greater forkbeard, syn. forked hake
Physiculus (*Pseudophycius*) *bachus* (Bloch and Schneider)	Red Cod (Oceania), syn. "hoka"
Pilodictis olivaris Rafinesque	Catfish (fresh-water)
Platichtys stellatus (Pallas), syn. *Paralichthys olivaceus* (Temminck and Schlegel)	Starry flounder (Pacific), syn. "hirame" (Japan)
Platycephalus indicus Linnaeus	Flathead (Pacific)
Platypoecilus maculatus	Mexican platyfish
Plecoglossus altivelis Temminck and Schlegel	"Ayu" (Japan)
Pleurogrammus azonus Jordan and Metz, syn. *P. monopterygius* (Pallas)	Atka mackerel
Pleuronectes cynoglossus (Linnaeus)	See *Glyptocephalus cynoglossus* (Linnaeus)
Pleuronectes (*Limanda*) *ferruginea* (Linnaeus)	Dab (Atlantic), longhead, yellowtail flounder
Pleuronectes flesus Linnaeus	Flounder (Europe), syn. whiteflake, fluke, butt
Pleuronectes microcephalus	Lemon sole (Atlantic)
Pleuronectes platessa Linnaeus	Plaice (Northeast Atlantic)
Pneumatophorus (*Scomber*) *colias* (Gmelin)	Chub mackerel
Pneumatophorus (*Scomber*) *diego* (Ayres)	Pacific mackerel
Pneumatophorus (*Scomber*) *japonicus* (Houttuyn)	Japanese mackerel
Pollachius pollachius (Linnaeus)	Pollock (Europe), syn. pollack
Pollachius virens (Linnaeus)	Coalfish, syn. saithe, coley, sea salmon
Polydactylus indicus Shaw	Indian salmon, syn. "dara" or "kuru"
Polynemus indicus (Shaw)	See *Polydactylus indicus*
Polyprion americanus (Bloch and Schneider)	Stone bass, syn. wreckfish
Polyprion oxygeneios (Bloch and Schneider)	Grouper (Oceania), syn. "hapuka" (Australia)
Pomacanthus spp.	Angelfish (United States); see also *Holacanthus* spp.
Pomatomus saltatrix (Linnaeus)	Bluefish, (United States), syn. elf (South Africa), anchova (Portugal)
Pomolobus aestivalis (Mitchill)	Alewife (United States, Canada)
Pomolobus pseudoharengus (Wilson)	Alewife (United States, Canada)
Pomoxis spp.	Crappie

Latin	English
Poronotus triacanthus (Peck)	Butterfish
Prionace glauca (Linnaeus)	Great blue shark
Prionotus spp.	Sea robin; see also *Peristedion* spp.
Psettichthys melanostictus Girard	Sand sole (flounder) (Pacific)
Psettodes erumei (Schneider)	Turbot (Indo-Pacific, Australia) "Kalankan" (Indonesia)
Pseudolabrus gracilis (Steindachner)	Wrasse (Japan)
Pseudolabrus japonicus (Houttuyn)	See *Pseudolabrus gracilis* (Steindachner)
Pseudopleuronectes americanus (Walbaum)	Lemon sole (Northwest Atlantic), syn. winter flounder (Northwest Atlantic)
Pygosteus pungitius (Linnaeus)	Arctic stickleback
Raja batis Linnaeus	Skate, syn. blue, bluet, grey skate
Raja brachyura Lafont	Blonde ray
Raja circularis Couch	Sandy ray
Raja clavata Linnaeus	Thornback ray
Raja erinacea Mitchill	Little skate
Raja fullonica Linnaeus	Shagreen ray
Raja lintea Fries	Sharp-nosed skate
Raja marginata Lacépède	Owl skate, syn. white-bellied skate, bordered skate, Burton skate
Raja microcellata Montagu	Painted ray
Raja montagui Fowler	Spotted, Homelyn ray
Raja naevus Müller and Henle	Cuckoo ray
Raja oxyrhynchus Linnaeus	Long-nosed skate
Raja radiata Donovan	Starry ray
Raja undulata Lacépède	Undulate, marbled ray
Rastrelliger kanagurta (Cuvier)	Indian Mackerel
Reinhardtius hippoglossoides (Walbaum)	Greenland halibut, syn. mock halibut, bastard halibut
Rhabdosargus globiceps (Cuvier)	White stumpnose (South Africa)
Rhina (*Squatina*) *squatina* Linnaeus	Monkfish, syn. angelfish (Europe), sharkray, fiddlefish
Rhombosolea spp.	Flounder (Oceania)
Rhombosolea plebeia (Richardson)	Dab (Oceania)
Rhombus laevis (Rondelet)	Brill (North Sea)
Rhombus (*Scopthalmus*) *maximus* (Linnaeus)	Turbot (North Atlantic)
Roccus saxatilis (Walbaum)	Striped bass
Rutilus rutilus caspicus (Jak.)	Caspian roach, syn. "vobla" (Russian)

Latin	English
Salmo clarki (Richardson)	Cutthroat trout
Salmo gairdneri irideus Richardson	Rainbow trout (North America), syn. steelhead trout
Salmo mykiss Walbaum	Kamchatka river salmon
Salmo penshinensis Pallas	Kamchatka salmon
Salmo salar Linnaeus	Salmon (Atlantic), syn. parr; see also huchen
Salmo sebago Girard	Sebago salmon
Salmo trutta (*fario*) Linnaeus	Brown trout
Salmo trutta trutta Linnaeus	Sea trout
Salvelinus spp.	Char
Salvelinus alpinus Linnaeus	Arctic char
Salvelinus fontinalis (Mitchill)	Brook trout (North America), syn. speckled trout
Salvelinus malma (Walbaum)	Dolly Varden
Salvelinus (*Christivomer*) *namaycush* (Walbaum)	Lake trout (North America), syn. Great Lakes char
Sarda australis	Bonito (Australia)
Sarda chilensis Cuvier and Valenciennes	Bonito (Chile)
Sarda lineolata (Girard)	Bonito (California)
Sarda orientalis (Temminck and Schlegel)	Stripped bonito
Sarda sarda Bloch	Bonito (Atlantic)
Sardina caerulea (Girard)	Pilchard (Pacific); see *Sardinops* (*Sardina*) *caerulea* Girard
Sardina (*Sardinops*) *melanosticta* (Temminck and Schlegel), syn. *Sardinops sagax melanosticta* (Schlegel)	Sardine (Northwest Pacific)
Sardina (*Sardinops*) *neopilchardus* (Steindachner)	Sardine (Australia)
Sardina pilchardus sardina Walbaum	Pilchard (Mediterranean)
Sardinella aurita Cuvier and Valenciennes	Sardine or pilchard (West Africa)
Sardinella fimbriata (Valenciennes)	Sardine (India)
Sardinella longiceps Valenciennes	Oil sardine (India)
Sardinella neopilchardus (Steinacher)	Pilchard or sardine (Oceania)
Sardinops (*Sardina*) *caerulea* Girard	Pilchard or sardine (Northeast Pacific)
Sardinops (*Sardina*) *ocellata* (Jenyns)	Pilchard or sardine (South Africa) syn. *Sardina sagax*
Sardinops sagax sagax (Jenyns)	Sardine (Southwest Pacific)
Scaphirhynchus platorynchus Rafinesque	Shovelnose sturgeon
Scardinius erythrophthalmus (Linnaeus)	Rudd, syn., red-eye
Sciaena aquila Linnaeus	Meagre, syn. maigre or shadefish

Latin	English
Sciaena diacanthus Günther	"Ghol" (India)
Scomber grex (Mitchill)	Mackerel (Caribbean)
Scomber japonicus Houttuyn, syn. *S. colias*	Pacific mackerel, syn. chub mackerel, blue mackerel
Scomber maculatus (Mitchill)	See *Scomberomorus maculatus*
Scomber scombrus Linnaeus	Mackerel (Atlantic)
Scomberomorus maculatus (Mitchill)	Spanish mackerel
Scomberomorus regalis (Bloch)	King mackerel, syn. great kingfish, pintado sierra; see also *Sierra cavalla* Cuvier
Scomberesox saurus (Walbaum)	Saury pike, syn. skipper
Scophthalmus maximus Linnaeus	See *Rhombus laevis* (Linnaeus)
Scylliorhinus capensis (Müller and Henle)	Dogfish (South Africa)
Scylliorhinus stellaris Linnaeus	Greater (large) spotted dogfish
Sebastes marinus (*marinus*) (Linnaeus)	Ocean perch, syn. Northeast Atlantic redfish, Norway haddock
Sebastes mentella (*marinus*) (Travin)	Redfish (Northwest Atlantic), syn. ocean perch
Sebastichthys capensis (Gmelin)	Jacopever (South Atlantic)
Sebastiscus marmoratus (Cuvier)	Rockfish (Japan)
Sebastodes inermis (Cuvier and Valenciennes)	Brown rockfish (China)
Sebastodes flammeus (Jordan and Starks)	Rockfish (Northwest Pacific)
Sebastomus rosaceus Girard	Rosy rockfish (Northeast Pacific), syn. corsair
Sebastosomus mystinus (Jordan and Gilbert)	Blue rockfish (Northeast Pacific)
Seriola lalandi Valenciennes	Yellowtail (Atlantic)
Seriola quinqueradiata (Temminck and Schlegel)	Yellowtail (Northeast Pacific)
Serrasalmus (*Rooseveltiella*) *nattereri* (Kner)	Piranha
Sierra cavalla Cuvier	King mackerel, syn, sierra; see also *Scomberomorus regalis* (Bloch)
Sillago spp.	Smelt (South Africa), syn. pescadinha (Portugal), whiting (Australia)
Siluris glanis (Linnaeus)	Sheatfish, syn. "som" (Russia)
Solea lascaris (Risso)	Sand sole (Europe)
Solea solea (Linnaeus)	Sole (Europe); see also *Solea vulgaris* (Day)
Solea (*Microchirus*) *variegata* (Donovan)	Thickback
Solea vulgaris (Day)	Syn. to *Solea solea* (Linneaus)
Somniosus microcephalus (Bloch and Schneider)	Greenland shark
Sphaeroides spp.	Puffers
Sphyraena spp.	Barracuda, syn. sea pike
Sphyraena picuda Bloch and Schneider	Barracuda (Japan)

Latin	English
Sphyrna zygaena Linnaeus	Hammerhead (shark)
Squalus acanthias (Linnaeus) syn. *Sq. suckleyi* (Girard)	Dogfish, syn. fluke, piked dogfish, rock salmon, sourdog
Squalus mitsukurii Jordan and Fowler	Dogfish (Japan)
Squatina squatina (Linnaeus)	Angelfish, syn. monkfish, fiddlefish
Stenodus leucichthys (Güldenstadt)	Inconnu
Stenodus leucichthys nelma (Pallas)	"Nelma" (Russian)
Stenotomus spp.	Porgies
Stenotomus versicolor (Mitchill)	Scup
Stereolepis gigas Ayres	Giant sea-bass, syn. black sea bass
Stizostedion canadense (Smith)	Sauger
Stizostedion vitreum glaucum (Hubbs)	Blue walleye (pike)
Stizostedion vitreum vitreum (Mitchill)	Walleye (pike)
Stromateus cinereus Bloch	White or silver pomfret (India), syn. "halwa"
Stromateus niger Bloch	Black pomfret (India), syn. "garangu"
Synaptura marginata Boulenger	Sole (South Africa), syn. tong; see also *Austroglossis microlepis* and *A. pectoralis*
Taractes princeps (Johnson)	Sea bream (Northwest Atlantic); see also *Brama* spp.
Tetrapturus spp.	Spearfish
Thaleichthys pacificus (Richardson)	Eulachon; Columbia River smelt
Theragra chalcogramma (Pallas)	Alaska pollock, syn. walleye pollock, "mintaí" (Russian), whiting, big-eye (Pacific) or Korean cod
Thunnus alalunga Bonnaterre	Albacore
Thunnus albacora (Lowe)	Yellowfin tuna
Thunnus atlanticus (Lesson)	Blackfin tuna
Thunnus thynnus (Linnaeus)	Bluefin tuna
Thunnus thynnus orientalis (Temminck and Schlegel)	Japanese tuna
Thymallus arcticus (Pallas)	Arctic grayling
Thymallus grubei	Grayling (China)
Thymallus thymallus (Linnaeus)	Grayling (fresh-water) (North America and Europe)
Thyrsites atun (Euphrasen)	Barracouta (Australia), snoek (South Africa)
Tiaroga cobitis Girard	Loach (minnow)
Tinca tinca (Linnaeus)	Tench
Torpedo spp.	Electric ray

Latin	English
Trachinotus blochii (Lacépède)	Pampano (Indo-Pacific)
Trachinotus carolinus (Linnaeus)	Common pampano
Trachinus draco Linnaeus	Great weever
Trachinus vipera Cuvier and Valenciennes	Angler, syn. lesser weever, stingfish
Trachurus declivis (Jenyns)	Yellowtail (Australia), syn. mackerel (Oceania)
Trachurus japonicus (Temminck and Schlegel)	Horse mackerel (Japanese)
Trachurus novae-zelandiae Richardson	Scad (Australia), syn. horse mackerel (Oceania)
Trachurus symmetricus (Ayres)	Horse mackerel (California)
Trachurus trachurus Linnaeus	Horse mackerel, capefish
Tribolodon hakonensis hakonensis (Günther)	Dace (Northwest Pacific)
Trichiurus lepturus Linnaeus	Scabbard-fish (Northwest Atlantic), hairtail (Japan)
Trigla capensis Cuvier	Gurnard (red) (South Africa), syn. "knoorhaan"
Trigla hirundo Linnaeus	Yellow gurnard
Urophycis chuss (Walbaum)	Squirrel hake
Urophycis tenuis (Mitchill)	White hake
Vimba vimba (Linnaeus)	Vimba (Baltic, Mediterranean, Caspian)
Vomer declivifrons Meek and Hildebrand	Moonfish (Pacific)
Vomer setapinnis (Mitchill)	Moonfish (Atlantic)
Wallago attu Bleeker	"Shirada" (India)
Xiphias gladius Linnaeus	Swordfish
Zeus australis Richardson	John Dory (Australia)
Zeus faber Linnaeus, syn. *Zeus capensis* Cuvier	John Dory (United Kingdom and South Africa)
Zeus japonicus Valenciennes	John Dory (Japan)

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